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RIDE QUALITY FOLLOW-UP

FINAL REPORT
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Submitted by

Dr. Sameh Zaghloul, P.E., P.Eng.*
Managing Senior Principal

Dr. Nenad Gucunski**
Professor

Dr. Hudson Jackson, P.E.,*** Pavement Specialist
Ms. Ivana Marukic, M.Sc.,*** Program Analyst
Ms. Parisa Shokouhi,** Graduate Research Assistant

●●●●●●●●●●●●

*Stantec Consulting Ltd.
150 Lawrence Bell Drive, Suite 108
Amherst, NY 14221

**Dept. of Civil & Environmental Engineering
Center for Advanced Infrastructure
& Transportation (CAIT)
Rutgers, the State University

***Stantec Consulting Ltd.
9 Princess Road, Unit D
Lawrenceville, NJ 08648

NJDOT Research Project Manager
W. M. (Lad) Szalaj

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e-mail addresses: szaghloul@stantec.com
gucunski@rci.rutgers.edu
hjackson@stantec.com
imarukic@stantec.com
parisash@rci.rutgers.edu

16. Abstract

The New Jersey Department of Transportation (NJDOT), as many other DOT's, moved towards utilizing a high-speed profiler to measure the International Roughness Index (IRI) as a part of the state smoothness acceptance specifications. Although high-speed profilers have been in use for long time as a tool to collect network-level IRI data for Pavement Management System (PMS) applications, however the use of this type of devices for project-level smoothness acceptance is relatively new. Therefore, NJDOT conducted a two-phase research study with the objectives of standardizing the testing protocols and identify/address the equipment related issues, such as repeatability, effects of testing speed and the use of high- and low- pass filters), manufacturers versus standard IRI computations (Proval and RoadRuf) and the impact of summary intervals.

Also, the study objectives included selecting a pavement profiling device as the Standard Pavement Profiler (SPP) for NJDOT, which will be used to calibrate other profilers, developing a procedure to calibrate and correlate other high speed profilers with NJDOT SPP and evaluating a standard software to process profile data and calculate IRI for NJDOT smoothness specifications. As a part of this study, detailed investigations were performed on the IRI algorithm and a new ride statistic was developed. Also, advanced profile analysis was performed to diagnose the profile characteristics that impact the rideability and user opinion. Comparisons were made between different ride statistics, traditional ride statistics (IRI, RN, PI and %DL) and the newly developed ride statistic.

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Table of Contents

Page

List of Figures

Page

List of Tables

BACKGROUND

Introduction

Ride quality, commonly referred to as pavement smoothness, is one of the most important highway characteristics that impact drivers. In addition, it plays a vital role in the long-term pavement performance, as well as in the pavement life cycle costs. Smoother pavements last longer and cost significantly less over their service lives. On the other hand, pavement sections that start with high initial roughness always have higher maintenance and rehabilitation cost, shorter service lives and significantly lower ride quality.

Roughness measurements are typically used to represent the user opinion of the ride quality. There are several methods to evaluate the roughness of pavements, and hence the ride quality. Profilographs and straightedges are used to measure the vertical deviations from a moving, fixed length reference plane (surface tolerance). The measured deviations are then compared with a maximum allowable value (in the range of 0.118 – 0.157 in). Areas with tolerance exceeding the allowable limit are identified and some remedial work may be performed.

Pavement smoothness can also be evaluated using roughness indices, such as the Ride Quality Index (RQI) and the International Roughness Index (IRI). The pavement longitudinal profile is measured using laser sensors. Simulation analyses are then performed on the measured profiles to estimate the vertical movements of a standard vehicle traveling at a constant speed. The estimated vertical movements are used to calculate roughness indices.

The New Jersey Department of Transportation (NJDOT) used a Rolling Straightedge (RSE) based specification for quality assurance of pavement smoothness. RSE is used to measure the surface tolerance, which is then used to evaluate the smoothness of newly constructed asphalt layers. Lengths of wheelpaths longer than six in. that exceed the tolerances > 1/8 in are identified as defective areas. The total length of these areas is then used to calculate the percentage defective length %Defective Length (%DL). One of the many disadvantages of this procedure is the time and effort associated with it. In addition, this approach requires lane closure and in some cases the results are misleading.

As a part of the on-going effort to improve the ride quality of NJDOT pavements, the NJDOT Bureau of Research conducted a study to evaluate the applicability of using automated highway profilers to replace the RSEs, Phase I study.

Phase I Project

A study was performed to evaluate the applicability of using automated profilers to replace RSE used by NJDOT to implement the department smoothness specifications. Two categories of profilers were considered in the study, low-speed profilers (two devices) and high-speed profilers (three devices), in addition to two of NJDOT RSEs. The scope of the study was limited to asphalt surfaced pavements. A Design of Experiment (DOE) was prepared to select the test sections. Three levels of initial smoothness were considered in the DOE, very smooth, smooth and relatively rough pavements.

Detailed field-testing included two RSEs, light-weight profilers and high-speed profilers. The testing with the light-weight profilers included data collection in the right and left wheel paths, three times each, at the speed recommended by the manufacturer. Also, three runs were performed at speeds of 10, 15 and 20 mph to investigate the impact of speed on the light-weight profiler measurements. The testing with the high-speed profilers included three repeated runs, as a minimum. Also, multiple runs at different speeds (40, 50 and 60 mph) were performed using one of the high-speed profilers.

Several analyses were performed on the collected data. These analyses included; preliminary analysis, RSE simulation, statistical analysis, effect of speed analysis and correlation analysis. The preliminarily analysis was performed on the results of the RSE inspection to select test sections that match the DOE requirements. RSE computer simulation analysis was performed on the collected profiles to simulate the RSE inspection. This analysis consisted of simulating a 10-ft straightedge over the profile and calculating the tolerance at the mid-point of the straightedge. This analysis was summarized as %DL, the length of pavement out of tolerance divided by the total length tested.

Several statistical analyses were performed on the collected and simulated data to investigate the equipment repeatability and the differences among devices, including the two RSEs. In these analyses, the F-Test and the Student t-Test were used. The analyses were performed on %DL measured with the RSEs and those from the simulation analysis, as well as on the IRI measured using the automated profilers. The effect of speed analysis was performed on the data collected using the light-weight profilers and the high-speed profiler.

Three correlation analysis studies were performed on the collected data. The objectives of these studies are to correlate the RSE measurements with the results of the simulation analysis performed on the profiles measured using the automated devices, to correlate the IRI measured with different devices and to correlate the IRI and %DL of the same device. Results of the analysis indicated that:

- The differences among devices are significant. This includes the %DL and IRI measurements. Also, the difference among the RSEs is significant and cannot be ignored.
- The speed effect on ARAN measurements is significant and not consistent, for both %DL and IRI.
- The differences between the RSE measurements and those of the light-weight profilers are significant and not consistent.
- The differences among IRI values measured using different devices/speeds are significant.
- RSE simulation provides reasonably accurate estimate of the RSE %DL. Results of the correlation between the measured and simulated %DL are found to be as high as 99 percent in some cases.
- Results of the correlation between IRI and %DL indicated that IRI does not sufficiently correlate with %DL, and therefore should not be used to replace %DL.

The study concluded that the use of automated profilers is beneficial and have many positive impacts, such as reduced inspection time, simultaneous provision of various roughness indices for improving pavement performance prediction models, and early detection of problems and subsequent remedial actions by contractors. The study however, also concluded that the accuracy of measurement varies significantly among profilers in terms of the recorded IRI values. This raised the issue of correlating various profilers against a common bench-mark.

The study recommended that NJDOT select an automated profiler to replace the RSE as its official and standard smoothness measuring equipment, and correlation models to be developed to calibrate/correlate other profilers with the standard profiler. Additional recommendations were made to select an indicator that better represents ride smoothness as compared to using %DL or IRI.

Objectives of Phase II

As a continuation of Phase I study, Phase II of the research study was initiated in 2003 with the following objectives:

- Select a pavement profiling device as the Standard Pavement Profiler (SPP) for NJDOT. SPP will be used to calibrate other profilers,
- Develop a procedure, using SPP, to be used to calibrate the NJDOT ride quality acceptance device and other high-speed profilers that may be used for quality control purposes,
- Develop a procedure to correlate high-speed profilers that may be used for quality control purposes with NJDOT SPP,
- Develop or evaluate a standard software to process profile data to calculate of NJDOT ride statistics for new and rehabilitated pavements.

Scope of Phase II

The scope of Phase II study is limited to asphalt concrete pavements. Three roughness categories are considered, which are:

- Very smooth pavements (Level 1) - (%DL) <= 1.5.
- Smooth pavements (Level 2) - 1.5 < %DL <= 3.5.
- Relatively rough pavements (Level 3) - %DL > 3.5.

Three test sections from each roughness category are desired. The right and left wheel path profiles of these test sections to be measured using different profiling devices. Repeated runs (3 runs) at different speeds (3 speeds for the high-speed profilers) are also planned.

To overcome the equipment problems of Phase I, two types of profiling devices are considered in Phase II, which are bench-mark devices and high-speed profilers. The bench-mark devices used in Phase II testing are:

- Rod and Level (R&L)
- Australian Road and Research Board (ARRB) Walking Profiler (WP)(1)

The high-speed profilers considered in Phase II testing are the NJDOT ARAN(2) manufactured by Roadway Corporation, a Dynatest 5051-MKIII-022 high-speed profiler(3) and a Stantec RT3000 manufactured by the International Cybernetics Corporation (ICC)(4).

FIELD TESTING PROGRAM

Test Section and Equipment Requirements

Table 1 shows the test section and equipment considered in the Phase II project. Three, 528-ft sections were selected for each roughness category.

Table 1. Design of Experiment.

Device	Roughness Category	Section Numbers	Wheel Paths Tested
Rod and Level	Very Smooth	S11, S12 & S13 Route 55	Left and Right
ARRB Walking Profiler			Left and Right
ARAN			Left and Right
Stantec RT3000			Left and Right
Dynatest 5051 MKIII-022			Left and Right
Rod and Level	Smooth	S1, S3 & S4 Route 195	Left and Right
ARRB Walking Profiler			Left and Right
ARAN			Left and Right
Stantec RT3000			Left and Right
Dynatest 5051 MKIII-022			Left and Right
Rod and Level	Relatively Rough	S23, S24 & S25 Route 18	Left and Right
ARRB Walking Profiler			Right*
ARAN			Left and Right
Stantec RT3000			Left and Right
Dynatest 5051 MKIII-022			Left and Right

* RWP & LWP of S23 and RWP only of S24 & S25

Site Selection and Preliminary Investigation

Figure 1 outlines the site selection process used in this project. The initial step involved the review of the condition of the test sections used in Phase I project and their suitability for Phase II. Also, some sections from 2002 construction season projects were considered. The as-built RSE measurements of these sections were reviewed and used to classify these sections into the appropriate initial smoothness group. Since R&L and WP surveys require lane closures, site conditions, such as traffic and number of lanes, were considered in the selection process. Test sections with high traffic volumes or with a single lane per direction were excluded from the initial list.

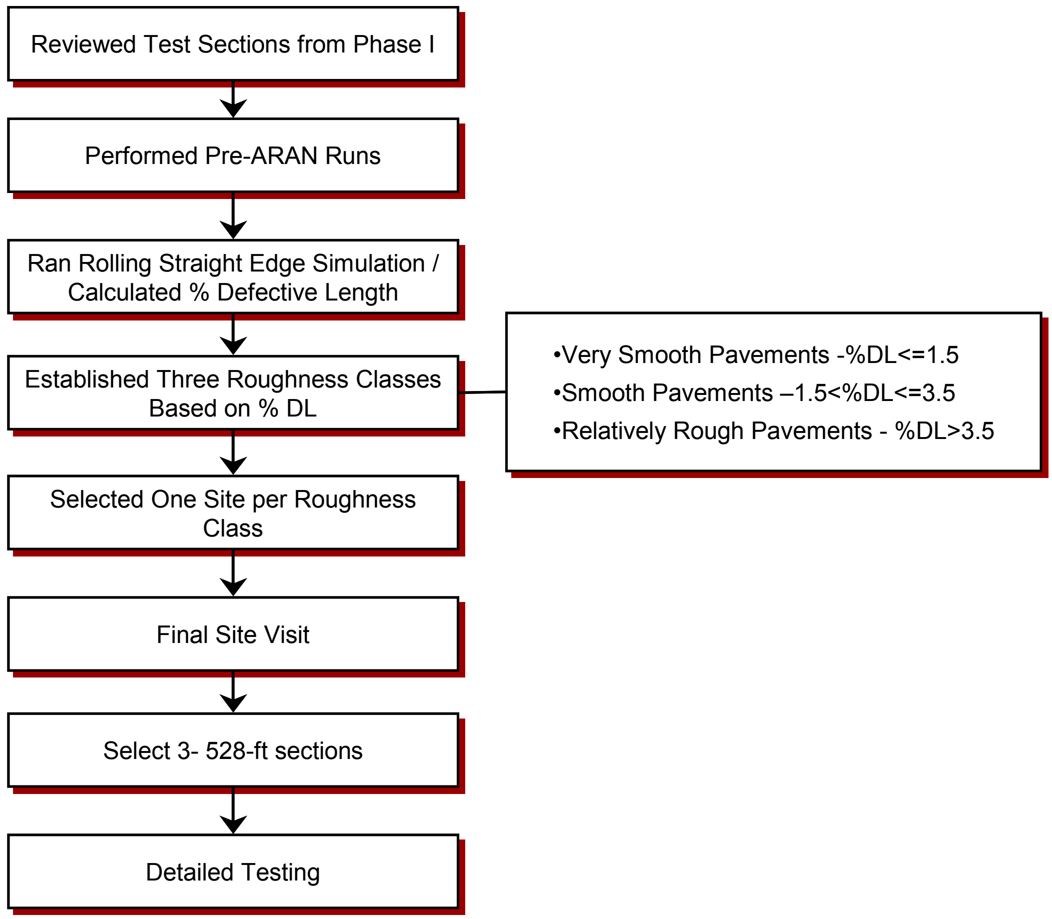


Figure 1. Test Section Selection.

The field-testing program of the project consisted of three stages. In the first stage, ARAN was used to scan the test sections of the initial list. RSE computer simulation was performed on the collected data to select test sections that satisfy Phase II requirements. The selected test sites are as follows:

- Very smooth – Route 55 Southbound from Milepost (MP) 26 to 25
- Smooth – Route 195 Westbound from MP 19 to 18
- Relatively Rough – Route 18 Northbound from MP 11.5 to 12.0

Three, 528-ft sections were selected from each site. It should be noted that the first two sites were also a part of Phase I.

Benchmark Profilers

In the second stage of the field-testing, three 528-ft sections were selected from each site. Two bench-mark devices were included in this study, the Australian WP and R&L.

R&L survey provides the highest accuracy of all devices. The major constraint of this survey is the time required to complete the survey. However, it was decided to perform this survey to evaluate WP, which is planned to be the bench-mark device for NJDOT.

The Australian Road and Research Board (ARRB) Walking Profiler[1] is a precision instrument designed to facilitate the efficient collection and presentation of continuous paved surface information such as profile and IRI[1]. The device uses on board electronics together with an in built DMI and a measuring beam with a footprint of 9.5 in to determine the pavement profile. The IRI accuracy of this device is ± 0.16 meters per km or ± 6.5 inches per 1000 yd. (on high quality pavements) and meets World Bank Class 1 Profilometry requirements. It also exhibits a very high correlation with rod and level derived IRI (R^2 = 0.988). More detailed information about WP is presented in Appendix A. Figure 2 shows a picture of WP.

Figure 2. Walking Profiler[1].

High-speed Profilers

Three high-speed profilers are considered in Phase II testing. These profilers are:

- NJDOT ARAN manufactured by Roadway Corporation, figure 3[2]
- Dynatest 5051-MKIII-022 high-speed profilers, figure 4[3]
- Stantec's RT3000 manufactured by ICC, figure 5[4]

The three profilers use laser sensors and accelerometers to measure the left and right wheel path profiles. Although all of these profilers use similar concept and based on the South Dakota Profiler, the data filtering/processing varies among them. More details about these profilers are provided in Appendix A.

Figure 3 ARAN High Speed Profiler[2].

Figure 4 Dynatest Road Surface Profiler[3].

Figure 5. ICC High Speed Profiler[4].

Field Testing

Bench-Mark Devices

Traffic control was provided by NJDOT to close the right lane of the selected sites for testing with both WP and R&L. Before testing with WP a field offset trim procedure was conducted as recommended by the manufacture. This was undertaken for all the sites to accustom WP to the ambient conditions, particularly temperature under which the surveys will be conducted. The LWP and RWP were marked using a contractor chalk line to ensure that both WP and R&L test along identical paths on the selected test sites. WP measurements were made along both wheel paths at a sampling rate of 9.5 inches with 3 runs per wheel path. The only exception of this was Route 18. A decision was made by NJDOT to refrain from testing the LWP along Route 18 using WP due to safety concerns for their field crew. Therefore, WP tests were performed on the RWP and LWP of Section S23 of Route 18 and only on the RWP of the other two sections of Route 18 (Sections S24 and S25). Figure 6 shows a picture of the WP test.

The LWP and RWP of each section were marked at 9.5-ft intervals, WP footprint. The selected test sections were then surveyed using the R&L and WP. Initially, it was planned to take R&L shots along both LWP and RWP at 9.5 in intervals. However, it was found that this process is very time consuming and labor intensive. Therefore, this protocol was implemented only on the LWP and RWP of 2 sections from the Route 55 site (Sections S11 and S13) because Route 55 was the first site tested with WP and R&L.

Statistical analysis was then performed on this detailed data to assess the impact of increasing the intervals to 19 in, 28.5 in, 38 in, 47.5 in and 57 in. In this analysis, the WP profiles (sampled at 9.5 in) were correlated with the R&L profiles sampled at different intervals (9.5 in to 57 in). Results of this correlation are shown in table 2. As can be seen, a very high correlation between the WP and R&L exists, regardless the R&L testing intervals. Therefore, it was established that the R&L survey could be conducted at larger spacing without affecting the accuracy of the results. Section 12 along Route 55 was therefore surveyed at 28.5-ft intervals. R&L testing was conducted according to ASTM E1364-2000, “Standard Test Method for Measuring Road Roughness by Static Level Method”. Figure 7 shows a picture of the R&L test.

Table 2. Impact of R&L Intervals on Correlation with WP.

Section	Spacing (in)	R^2
S11L	9.5	1
S11R	9.5	0.9999
S13L	9.5	0.9929
S13R	9.5	0.9923
S11L	19	1
S11R	19	1
S13L	19	0.9928
S13R	19	0.993
S11L	28.5	1
S11R	28.5	1
S13L	28.5	0.9969
S13R	28.5	0.9972
S11L	38	1
S11R	38	1
S13L	38	0.9933
S13R	38	0.9935
S11L	47.5	1
S11R	47.5	1
S13L	47.5	0.997
S13R	47.5	0.9972
S11L	57	1
S11R	57	1
S13L	57	0.9956
S13R	57	0.9959

High-Speed Profilers

The high-speed profilers used in this study included profilers from three different manufacturers, namely ICC (RT3000), Roadware (ARAN) and Dynatest. Each profiler was equipped with at least 2 laser sensors and 2 accelerometers. Pavement profiles along both wheel paths were measured and recorded at a sampling rate in the range of 1-6 in.

Each high-speed profiler was setup as per the manufacturer recommendations. Table 3 shows a summary of the set up parameters for each of the high-speed profilers. Testing was conducted according to ASTM E-950-98 “Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial”. The selected test sections (a total of 9) were tested with the high-speed profilers at 3 speeds (40, 50 and 60 mph), and 3 runs at each speed.

Table 3. High-speed Profilers Setup Parameters.

	ARAN	Dynatest	RT3000
Filter Cutoff (ft)	300	300	None
Sampling Interval (in)	3.97	0.98	3.218
Station Interval (ft)	52.8	52.8	52.8

It should be noted that, unfortunately, due to delays caused by equipment breakdown, weather, budget constraints, etc, Route 18 sections were not tested with all devices within the same timeframe. Some testing was performed in the fall, while other testing was performed in the spring. Significant deterioration of Route 18 condition was observed in the spring testing. Testing with the high-speed profiler for Route 18 was performed in the fall, while testing with the WP was performed in late winter/early spring. R&L testing was started in the fall and completed in the spring.

Figure 6. Field Testing with the Walking Profiler.

Figure 7. Rod and Level Survey.

DATA ANALYSIS

Two categories of analysis were performed on the profiles collected using the bench-mark and high-speed profilers.

The first category is concerned with the impact of using different devices on the reported pavement roughness, regardless the index used to evaluate and report the observed roughness. In this category of analysis, the following issues were addressed:

- Profile comparisons
- Equipment Related Issues
  - Repeatability
  - Effects of testing speed
  - Filtering Effects
- Manufacturers, Proval and RoadRuf Computed IRI
- Summary interval sensitivity analysis

Although the purpose for which Federal Highway Administration (FHWA) is using IRI, network-level management application, is significantly different from the scope of this project, detailed project-level investigation, IRI was used in the analysis presented earlier to investigate the impact of testing parameters on the reported results. The reason for that is the wide spread of using IRI, nation and world wide, and the familiarity with the IRI scale. Although it is true that each organization is more familiar with the organization specific indices, such as the RQI and %DL for NJDOT, however this experience is a sort of local experience. Therefore, it was felt that using IRI to illustrate the impact of testing parameters, such as speed, equipment,….etc., will facilitate transferring this effort and knowledge to other states.

The second category of analysis touches on the use of different ride statistics, currently available or newly developed as a part of this study, to evaluate, explain and report the observed roughness. Also, in this category another approach, advanced profile analysis, is considered to explain and diagnose the observed roughness. In this section of the report, the results of the first category of analysis are presented. Based on the analysis performed and presented in this section, NJDOT SPP was selected and a calibration/correlation procedure was developed to calibrate/correlate other profilers with SPP. This procedure is presented in the following section. The use of other traditional ride statistics, which are currently available is discussed; and newly developed ride statistics and advanced profile analysis are presented later in this report.

Caution is advised through out this report when reviewing the results for the relatively rough sections (Route 18) because testing along Route 18 by the profilers was not conducted within the same time frame. Some testing was conducted before winter and due to mostly NJDOT equipment and scheduling issues, testing was continued after winter. Route 18 was selected in November and testing was conducting with Dynatest and ICC profilers in December 2003. Some R&L testing was done in December 2003 and the rest after winter. WP testing was conducted after winter. Unfortunately, the section deteriorated significantly over the winter months and due to budget limitations, testing with all participating profilers could not be rescheduled. Results from Route 18 are therefore for the most part used with caution.

Profile Comparisons

Most high-speed profilers use a moving average filter with the capability of specifying different base or cutoff lengths. A moving average filter replaces each profile point with the average of several adjacent points. It is common practice to use a high pass filter with a 300-ft base length to remove wavelengths greater than 300-ft from the measured profile. Also, a low pass filter is sometimes used to remove wavelengths less than the specified base length. The IRI routine uses a low pass filter with a 10 in cutoff length.

Raw profiles collected by R&L and WP are unfiltered, so the grade of the roadway is integrated in the data. In order to establish a base line for comparing the profiles, a high pass moving average filter with a cutoff length of 300-ft was selected. This cutoff is currently used by NJDOT Pavement Management Unit (PMU) for network inventory data collection. “Raw” profiles provided by NJDOT ARAN and Dynatest were pre-filtered at this cutoff length, while those from RT3000 were unfiltered.

Bench-Mark Devices

Visual assessment of the profiles collected using R&L and WP for both LWP and RWP of the 9 test sections indicates that the two devices provide very similar results. Figures 8 to 10 show samples of R&L and WP profiles for the RWP of a very smooth (Route 55), smooth (Route 195) and relatively rough (Route 18) sections, respectively, using 300-ft high pass filter. As can be seen from these figures, the measurements of R&L and WP are almost identical. A complete set of the profiles measured using R&L and WP is presented in Appendix B. These results confirm the assumption that WP can be used as a bench-mark device to calibrate other devices and therefore will be selected as NJDOT SPP.

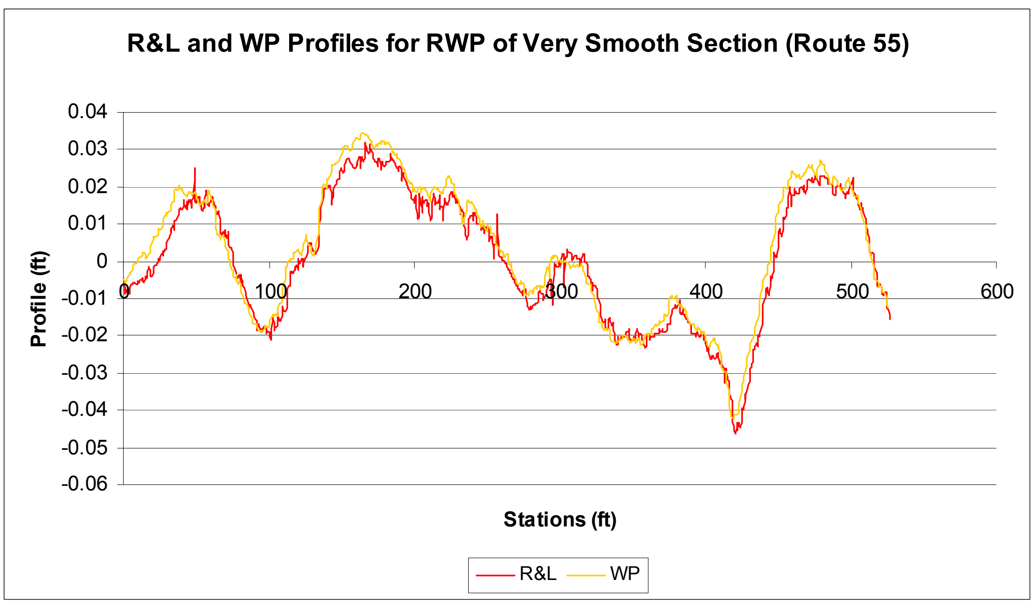


Figure 8. R&L and WP Profiles for RWP of a Very Smooth Section (Route 55).

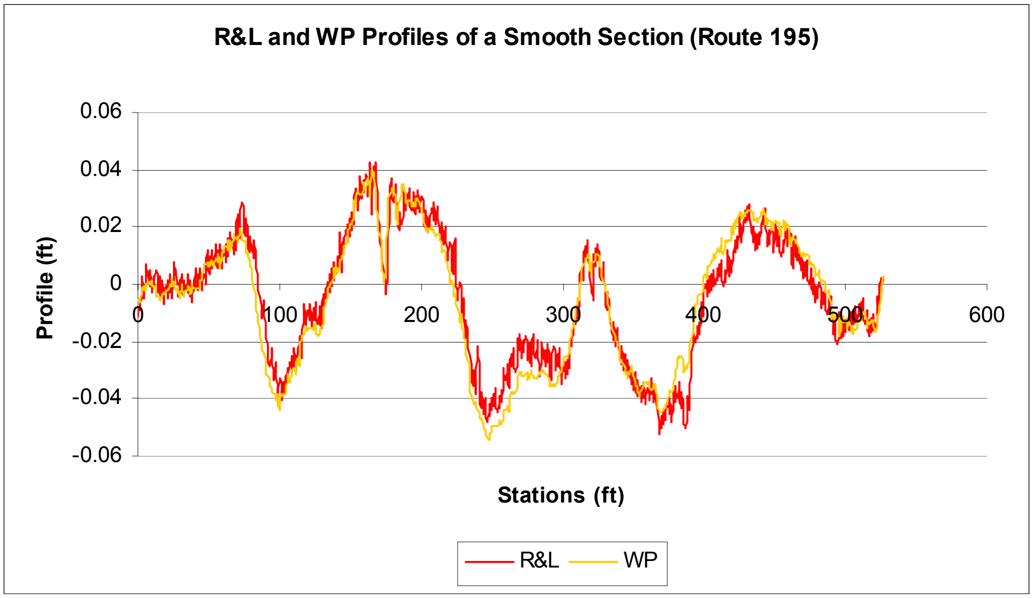


Figure 9. R&L and WP Profiles for RWP of a Smooth Section (Route 195).

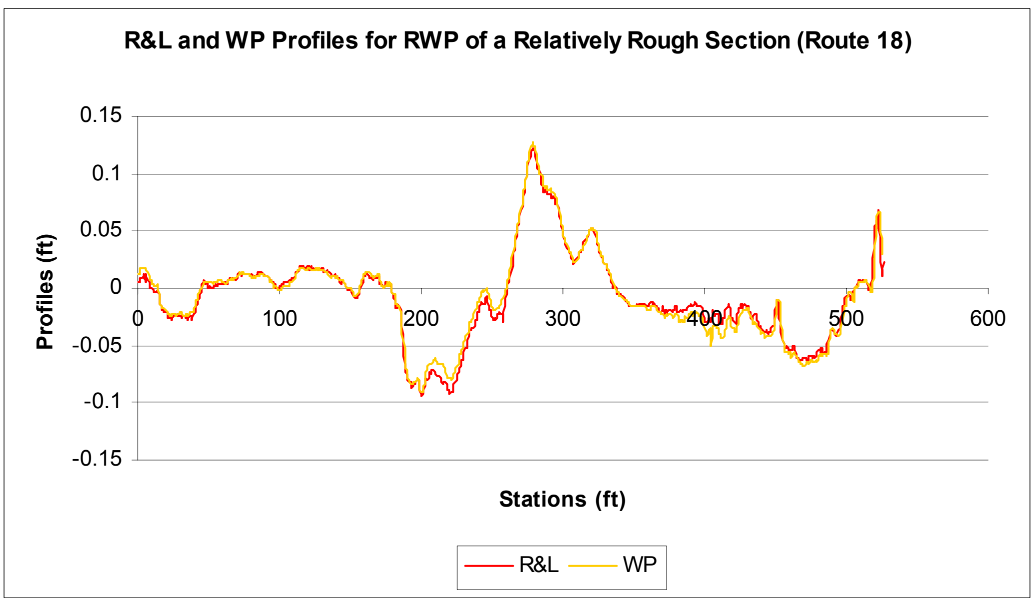


Figure 10. R&L and WP Profiles for RWP of a Relatively Rough Section (Route 18).

High-Speed Profilers

The profiles measured with the high-speed profilers were compared with the corresponding profiles measured using the bench-mark devices. Figures 11 to 13 show samples of these comparisons for a very smooth (Route 55), smooth (Route 195) and relatively rough (Route 18) sections, respectively. A complete set of the results is presented in Appendix B. As can be seen, for some sections the profiles matching reasonably well. However, in some cases, pronounced differences are observed between the high-speed profilers and R&L/WP.

In general, it is hard to come up with an objective way to compare profiles. Profiles can only be compared visually or by further analyzing them and calculating some indices or frequencies. Therefore, no further comparison of the raw profiles will be presented to avoid any unsupported conclusions.

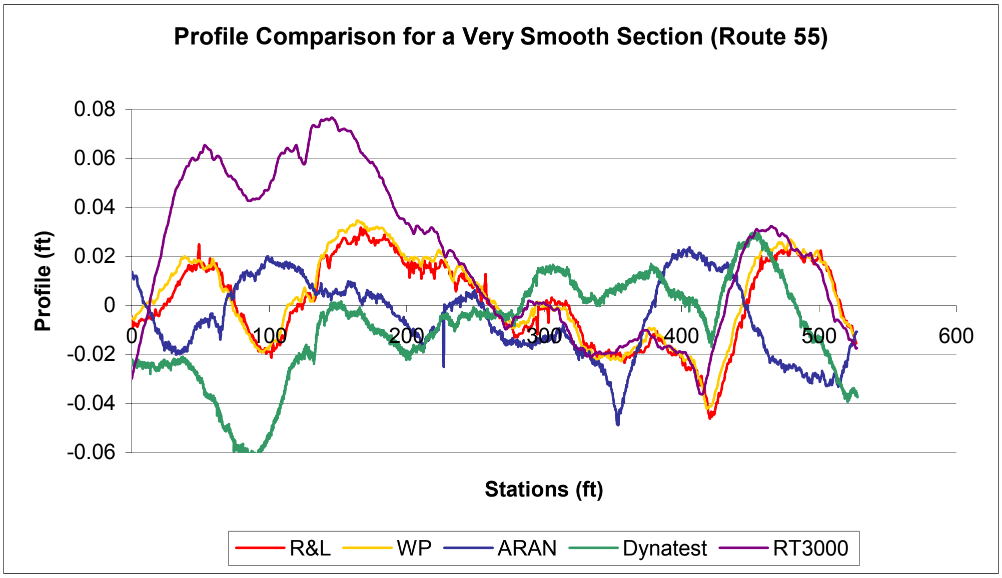


Figure 11. Profile Comparison for a Very Smooth Section (Route 55).

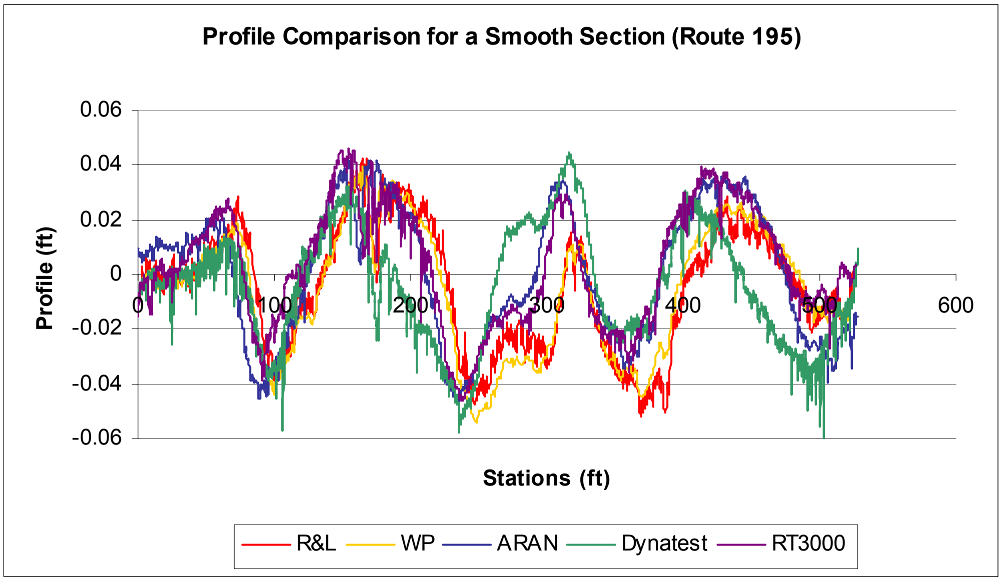


Figure 12. Profile Comparison for a Smooth Section (Route 195).

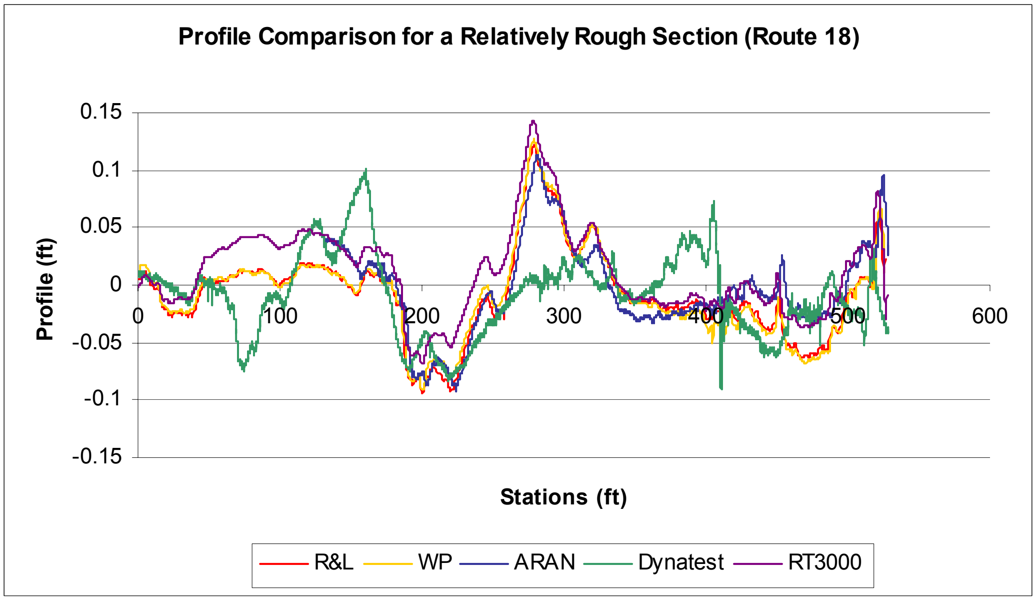


Figure 13. Profile Comparison for a Relatively Rough Section (Route 18).

Equipment Related Issues

Several equipment related issues were identified in Phase I study that need to be addressed to ensure compatible results. These issues include:

- Repeatability
- Effects of testing speed
- Filtering Effects

Common measures should be established to be able to evaluate different devices with respect to these issues. Since IRI is the most commonly used roughness index, IRI was used in the analysis performed to address the above-mentioned issues. In addition, since there are observed differences between the IRI values calculated using public-domain software packages, such as RoadRuf, and those reported by the devices, as will be presented later in this report, RoadRuf was used in the analysis presented in this section. RoadRuf was developed by the University of Michigan Transportation Research Institute for the FHWA.

Equipment Repeatability

The repeatability of each device was evaluated by performing multiple runs at the same speed. The measured profiles were split into 52.8-ft sub-sections and RoadRuf was used to calculate the IRI of these sub-sections. The sub-section IRI values for the repeated runs were then compared. The full results of these comparisons are presented in Appendix C of this report. Samples of these results for a very smooth section (Route 55), smooth section (Route 195) and relatively rough section (Route 18) are shown in figures 14 to 25. The comparison results indicate that the repeatability of all devices is in general good. The variability among repeated runs for of the 52.8-ft sub-sections can be summarized in terms of average and standard deviation, as shown in table 4.

Table 4. Average and Standard Deviation of Differences between Runs.

Route 55 (very smooth)	Average IRI (in/mi)	Std. Dev
WP	4.63	3.55
ARAN	6.19	5.41
RT3000	4.96	4.26
Dynatest	2.41	2.07
Route 195 (smooth)	**Average IRI (in/mi)**	**Std. Dev**
WP	5.73	4.54
ARAN	16.35	15.45
RT3000	10.61	11.15
Dynatest	9.44	10.94
Route 18 (relatively rough)	**Average IRI (in/mi)**	**Std. Dev**
WP	67.14	107.11
ARAN	67.63	72.36
RT3000	35.55	47.06
Dynatest	24.09	30.12

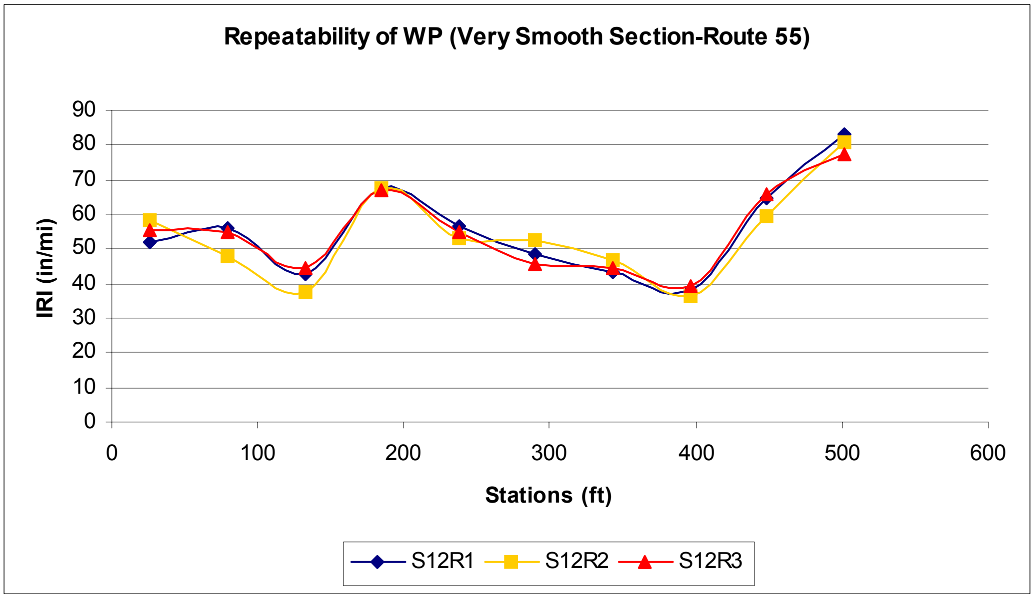


Figure 14. Repeatability of Walking Profiler (Very Smooth Section – Route 55).

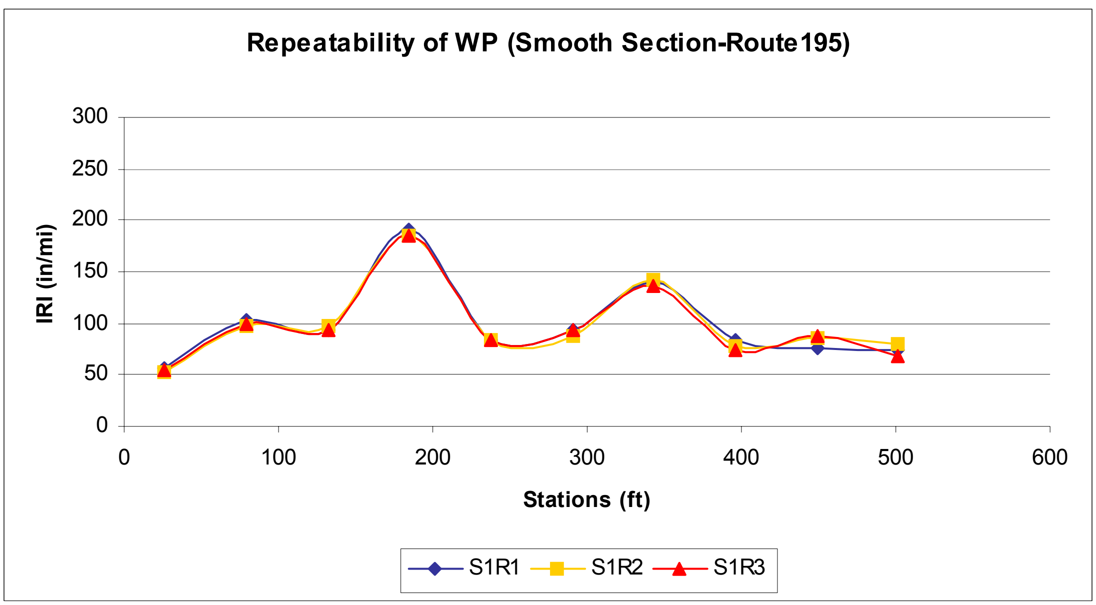


Figure 15. Repeatability of Walking Profiler (Smooth Section – Route 195).

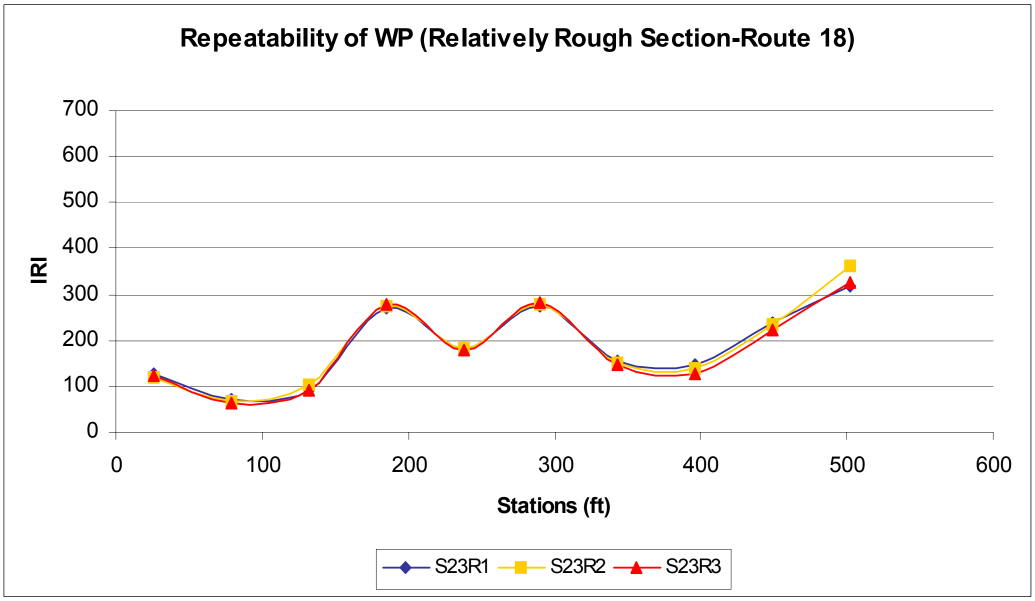


Figure 16. Repeatability of Walking Profiler (Relatively Rough Section – Route 18).

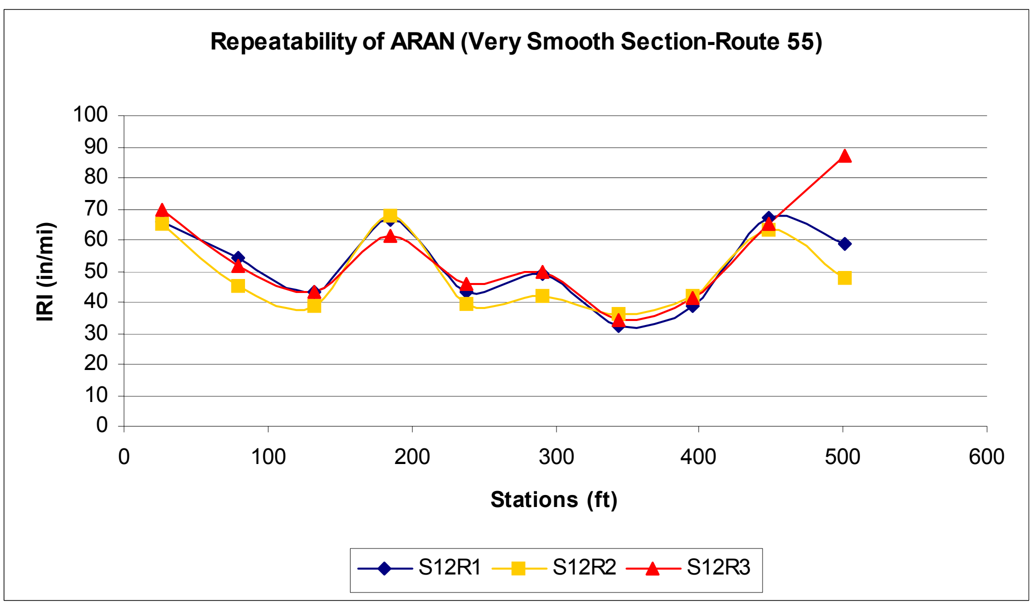


Figure 17. Repeatability of ARAN (Very Smooth Section – Route 55).

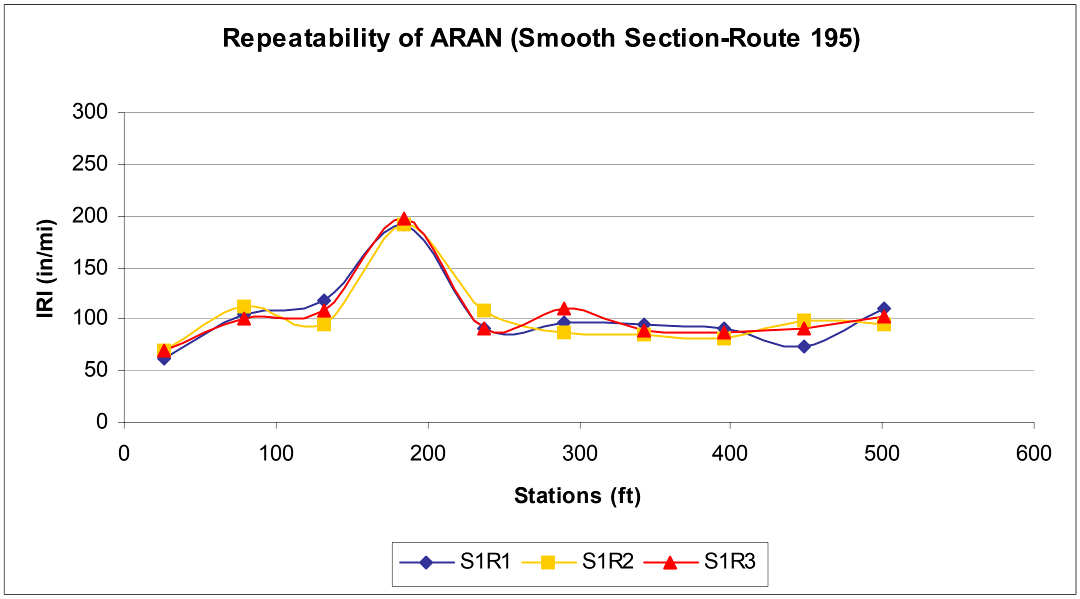


Figure 18. Repeatability of ARAN (Smooth Section – Route 195).

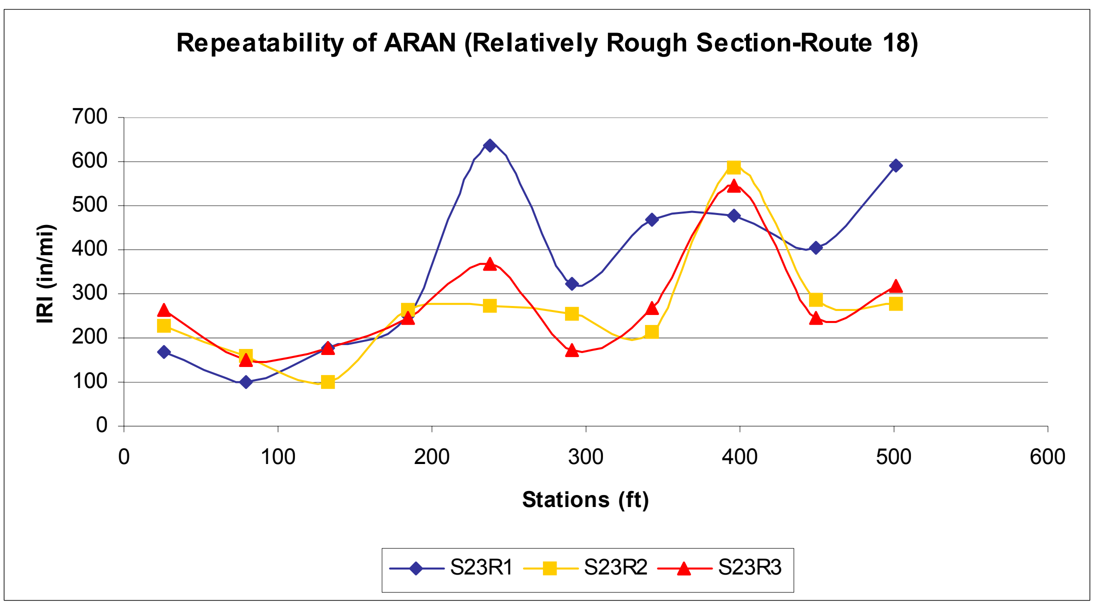


Figure 19. Repeatability of ARAN (Relatively Rough Section – Route 18).

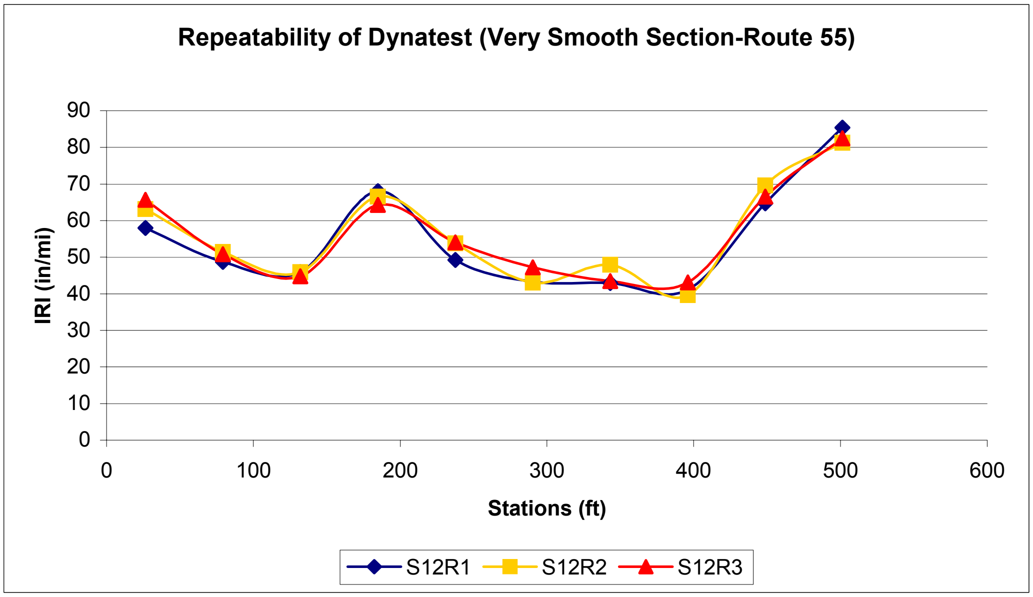


Figure 20. Repeatability of Dynatest (Very Smooth Section – Route 55).

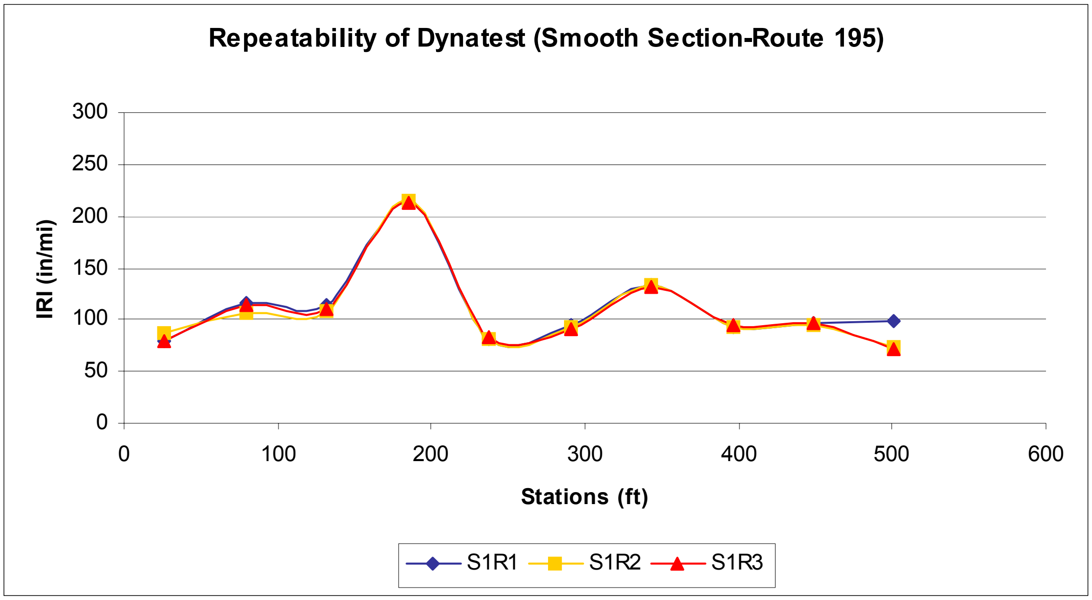


Figure 21. Repeatability of Dynatest (Smooth Section – Route 195).

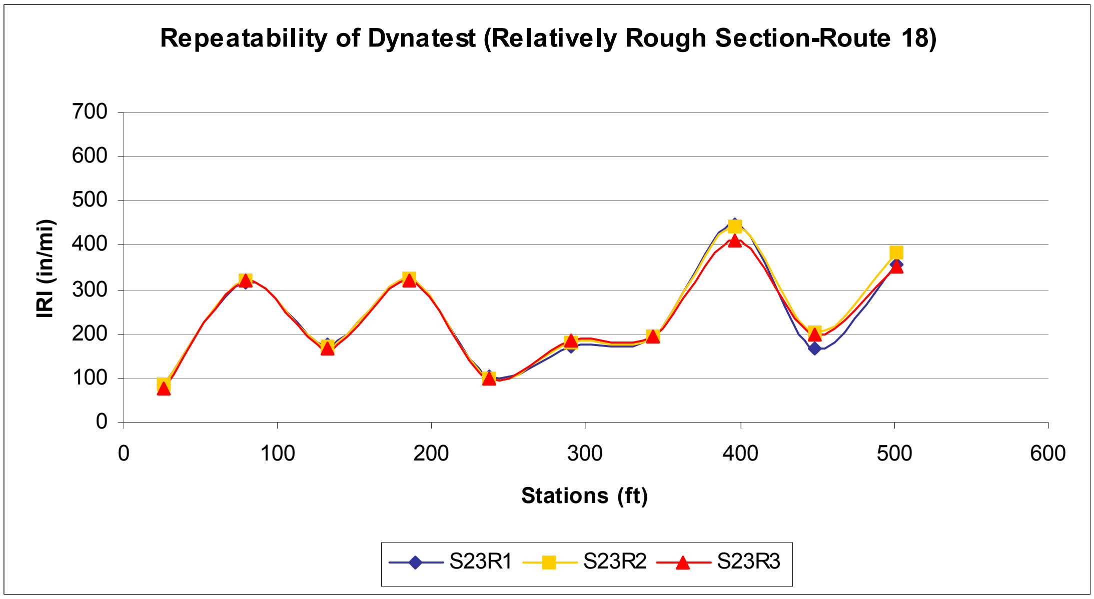


Figure 22. Repeatability of Dynatest (Relatively Rough Section – Route 18).

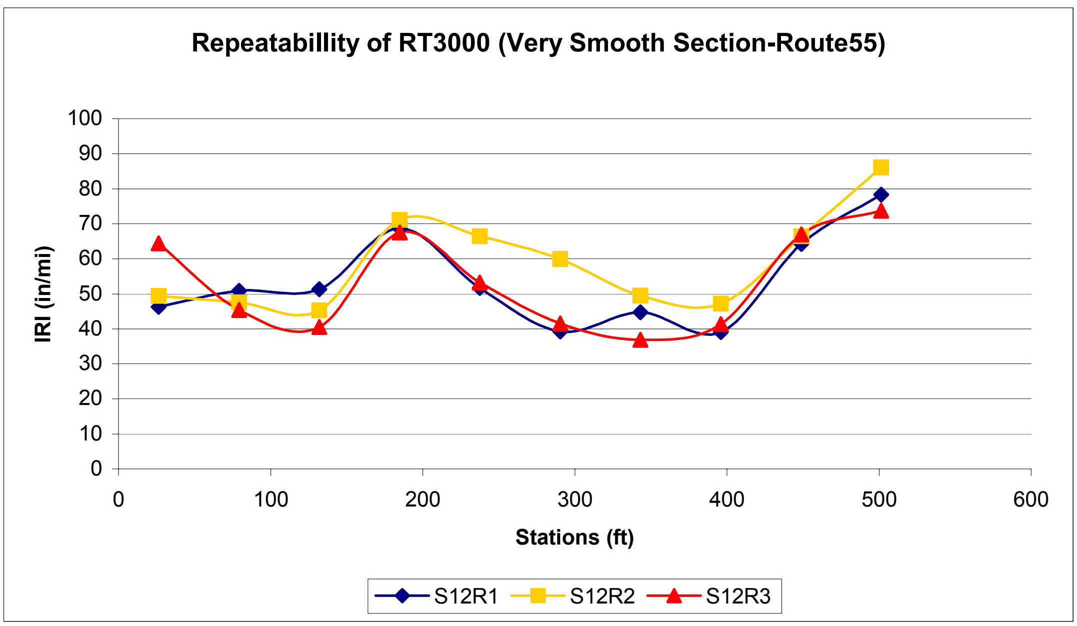


Figure 23. Repeatability of RT3000 (Very Smooth Section – Route 55).

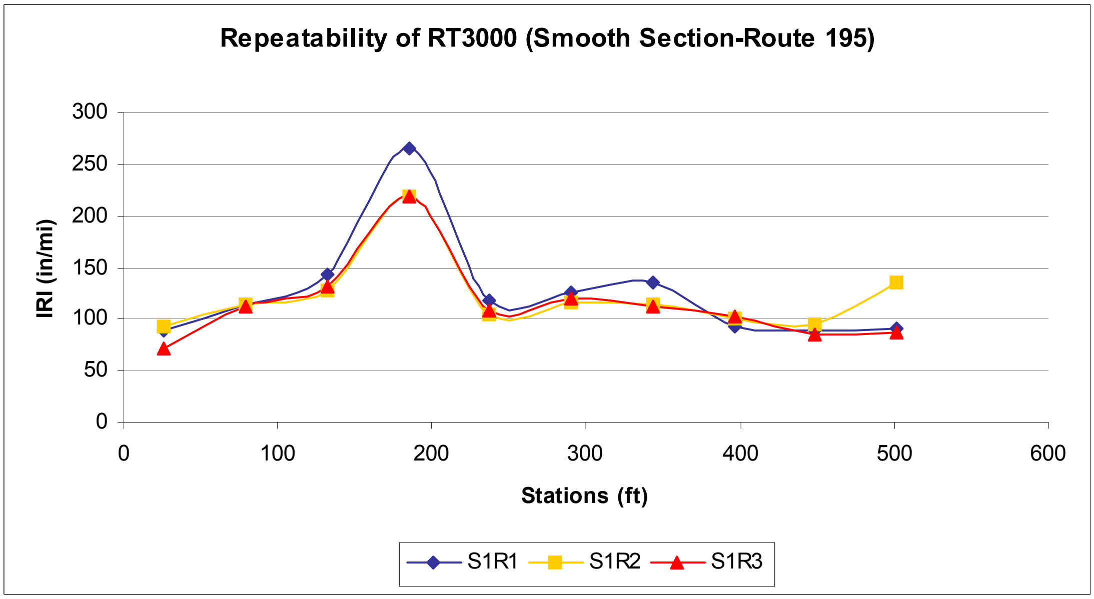


Figure 24. Repeatability of RT3000 (Smooth Section – Route 195).

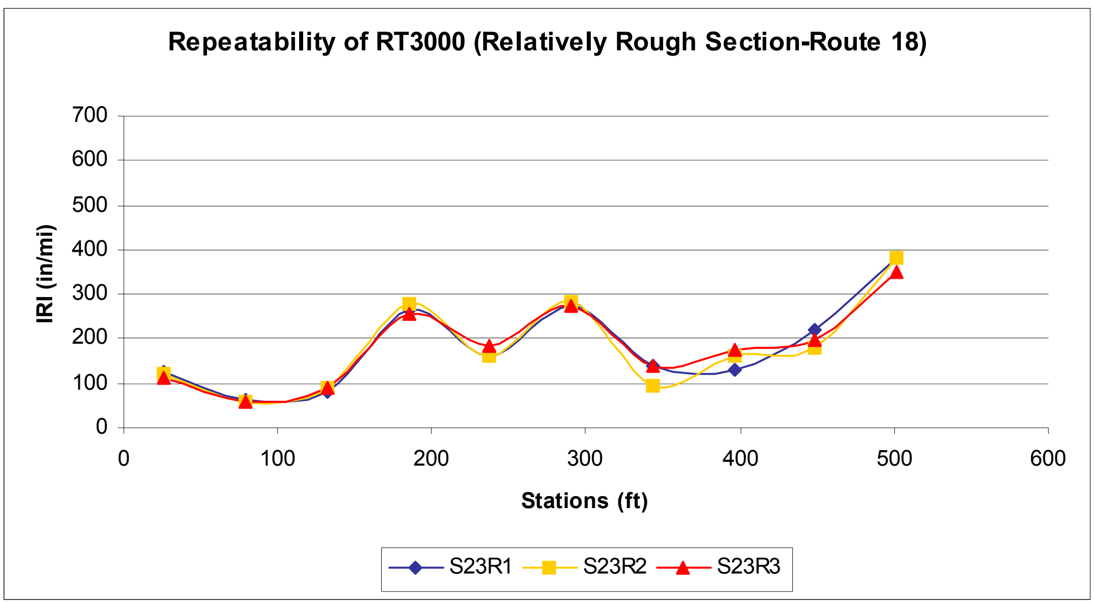


Figure 25. Repeatability of RT3000 (Relatively Rough Section – Route 18).

Effects of Testing Speed

Multiple speed runs were performed by each of the high-speed profilers to evaluate the speed dependency of the device. The measured profiles were then filtered and processed using RoadRuf to calculate the IRI at different speeds for a common HP filter cutoff length of 300-ft. A complete set of results of this analysis is presented in Appendix B of this report. Samples of these results for a very smooth section (Route 55), smooth section (Route 195) and relatively rough section (Route 18) are shown in figures 26 to 34.

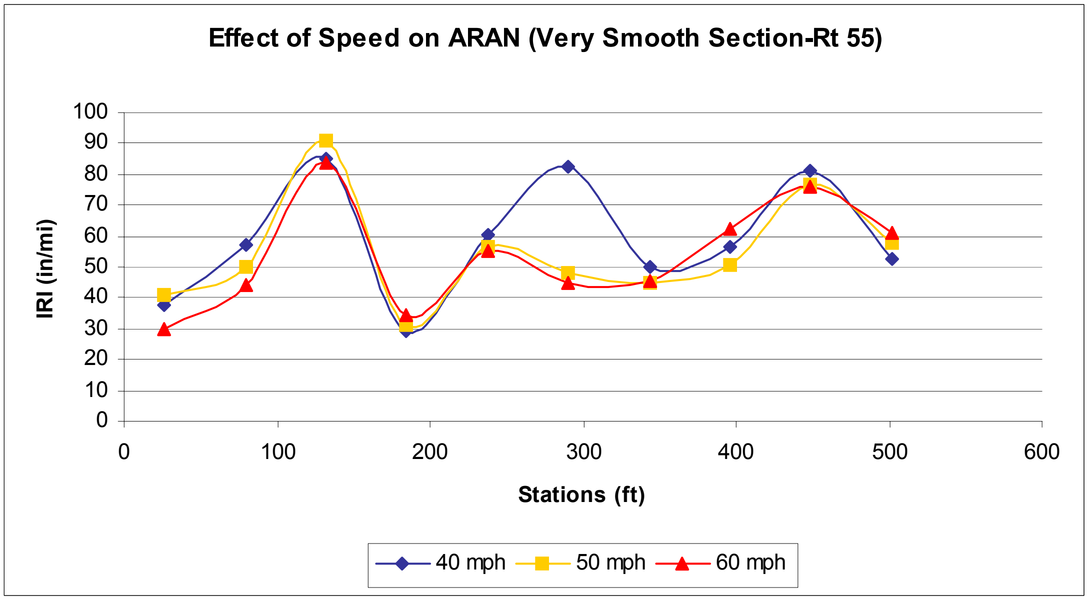


Figure 26. Effect of Speed on ARAN (Very Smooth Section – Route 55).

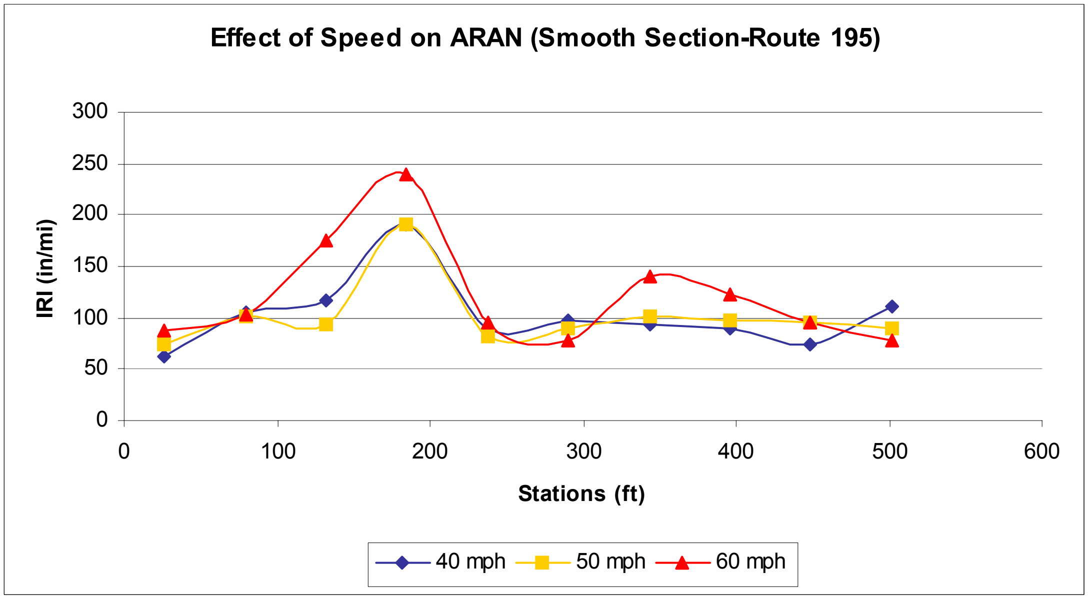


Figure 27. Effect of Speed on ARAN (Smooth Section – Route 195).

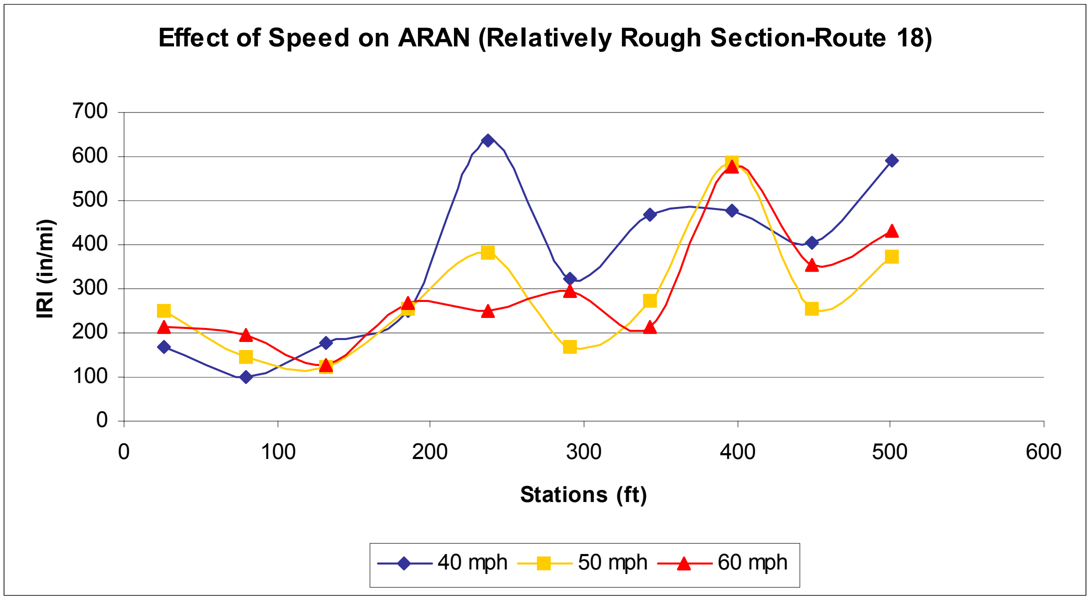


Figure 28. Effect of Speed on ARAN (Relatively Rough Section – Route 18).

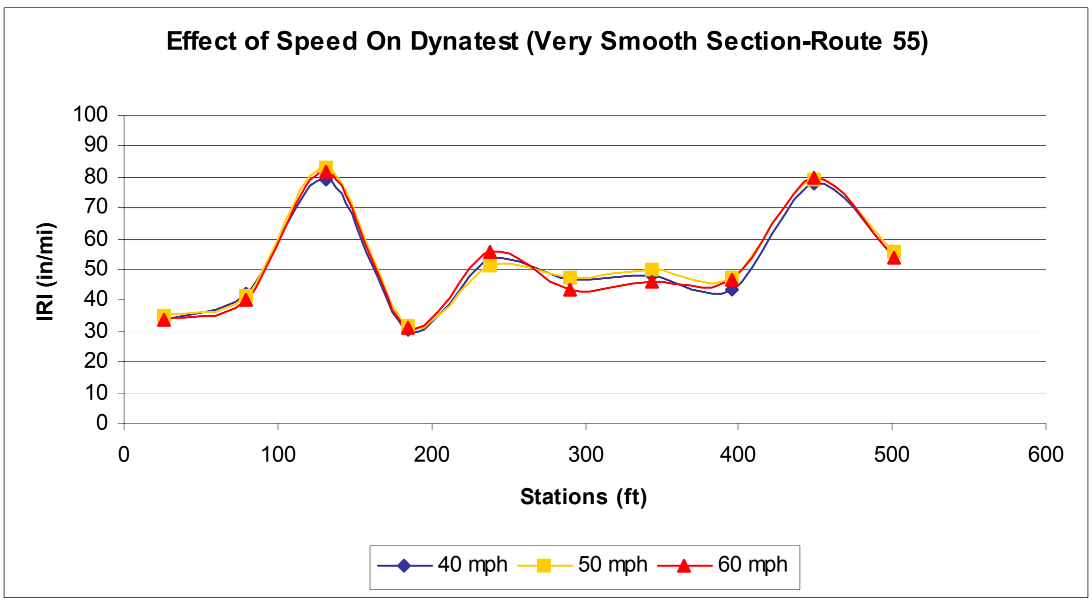


Figure 29. Effect of Speed on Dynatest (Very Smooth Section – Route 55).

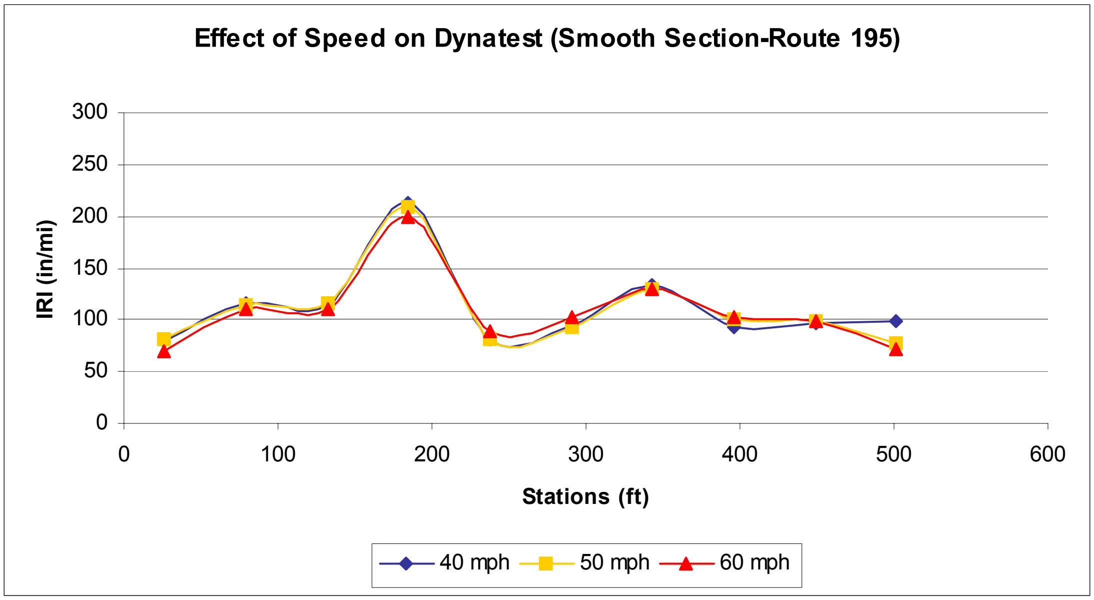


Figure 30. Effect of Speed on Dynatest (Smooth Section – Route 195).

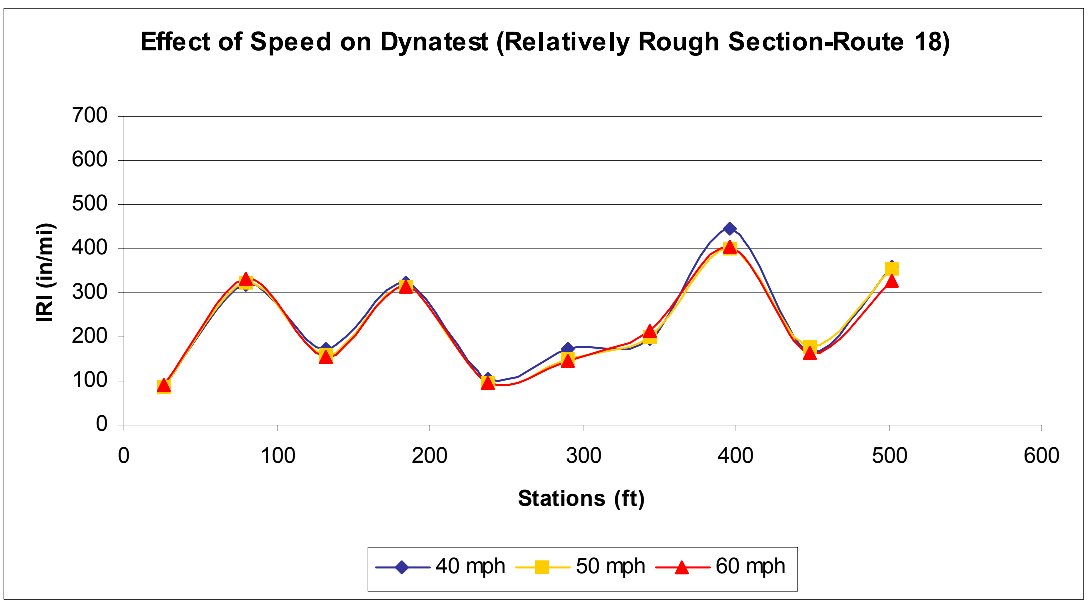


Figure 31. Effect of Speed on Dynatest (Relatively Rough Section – Route 18).

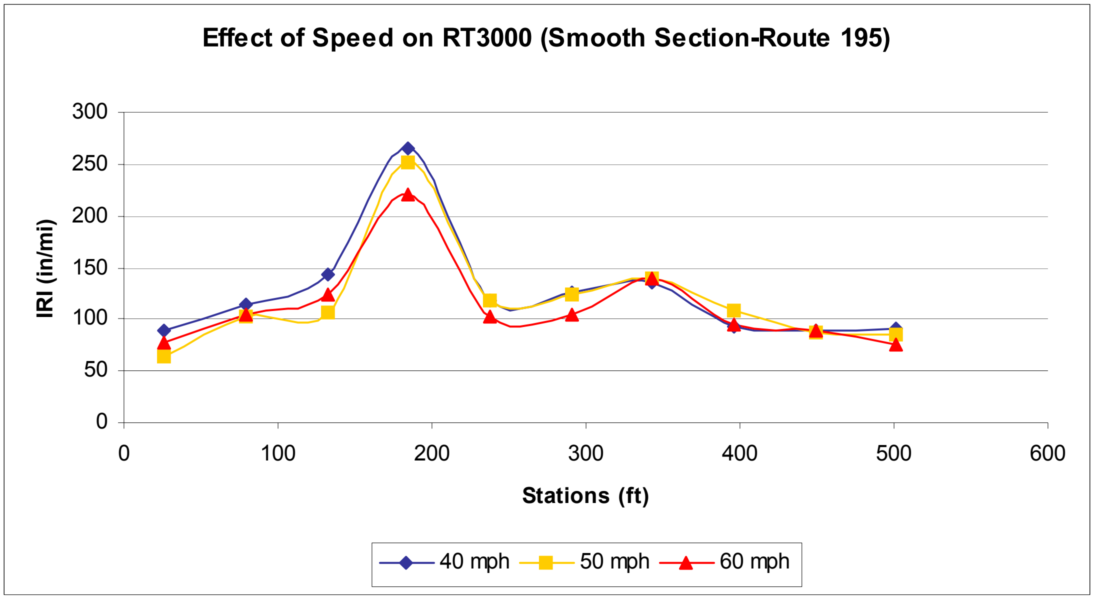


Figure 33. Effect of Speed on RT3000 (Smooth Section – Route 195).

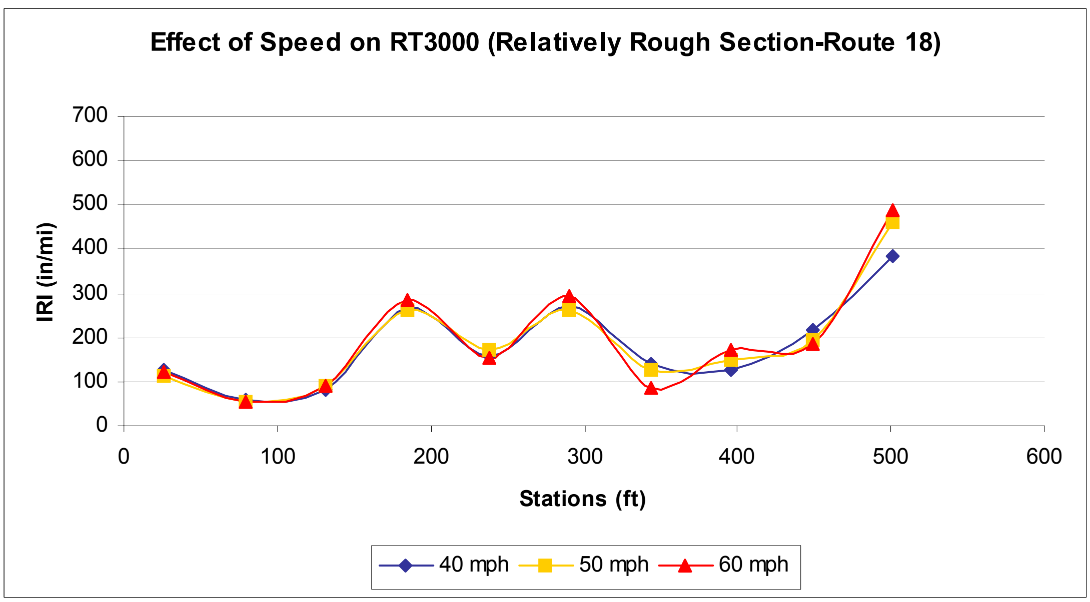


Figure 34. Effect of Speed on RT3000 (Relatively Rough Section – Route 18).

As can be seen, speed can have a significant impact on the measured IRI, especially for ARAN. It was found that the differences in IRI at different speeds can be as high as 89 in/mi for some equipment. However, there is no consistent trend for the speed impact on IRI. Using the IRI values at 40 mph (IRI40) as reference, a comparison was made between the average of the three runs at each speed. The differences between IRI at a speed of 40 mph and that at speeds of 50 and 60 mph for the 52.8-ft sub-sections are summarized in tables 5a and 5b for smooth and very smooth sections. Table 5a shows the maximum difference between corresponding speed runs, while table 5b shows the average and standard deviation for the same data. Comparison for the relatively rough sections (Route 18) is not included in the table due to the unreliability of the results, as explained earlier.

Table 5a. Maximum IRI Differences at Various Speeds for 52.8-ft Sub-sections.

Route 195 (smooth)	IRI40-IRI50	IRI40-IRI60	IRI50-IRI60
RT3000	55.66	77.82	48.39
ARAN	62.80	89.75	89.96
Dynatest	77.05	58.66	77.73
Route 55 (very smooth)	**IRI40-IRI50**	**IRI40-IRI60**	**IRI50-IRI60**
RT3000	19.33	26.76	21.39
ARAN	34.04	37.22	38.94
Dynatest	15.35	17.79	9.10

Table 5b. Average and Standard Deviation of IRI Differences at Various Speeds for 52.8-ft Sub-sections.

Route 55 (very smooth)	IRI40-IRI50		IRI40-IRI60		IRI50-IRI60	
	Average	**Std. Dev**	**Average**	**Std. Dev**	**Average**	**Std. Dev**
ARAN	4.72	5.29	7.11	5.84	4.75	4.05
RT3000	7.77	6.08	6.40	5.44	3.01	3.87
Dynatest	1.65	1.99	2.04	3.03	1.05	1.16
Route 195 (smooth)	**IRI40-IRI50**		**IRI40-IRI60**		**IRI50-IRI60**	
	Average	**Std. Dev**	**Average**	**Std. Dev**	**Average**	**Std. Dev**
ARAN	9.30	7.70	16.25	15.32	13.76	12.23
RT3000	4.98	5.82	6.40	11.17	7.59	12.32
Dynatest	7.19	8.30	8.10	6.91	10.45	9.30

Although the 52.8-ft IRI values show some speed dependence, the same comparison when it was performed at the section level (IRI for the 528-ft) indicated much less variation in IRI with speed, as shown in figures 35 and 36. The effect of summary interval on IRI is discussed later in this report. This brings up the question of the suitability of IRI as a roughness measure for smoothness acceptance of new or rehabilitated pavement. IRI is a suitable ride statistic for network level inventory to provide an overall assessment of the pavement roughness. At project level, however, IRI appears to be very sensitive to the summary interval as well as testing speed.

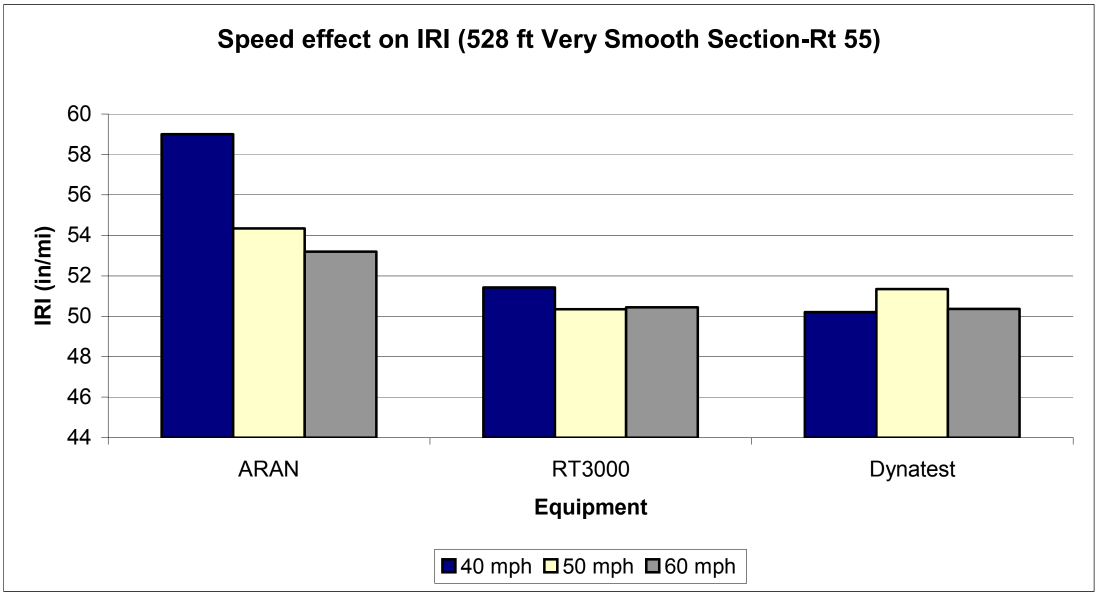


Figure 35. Speed Effect on IRI (528-ft Very Smooth Section – Route 55).

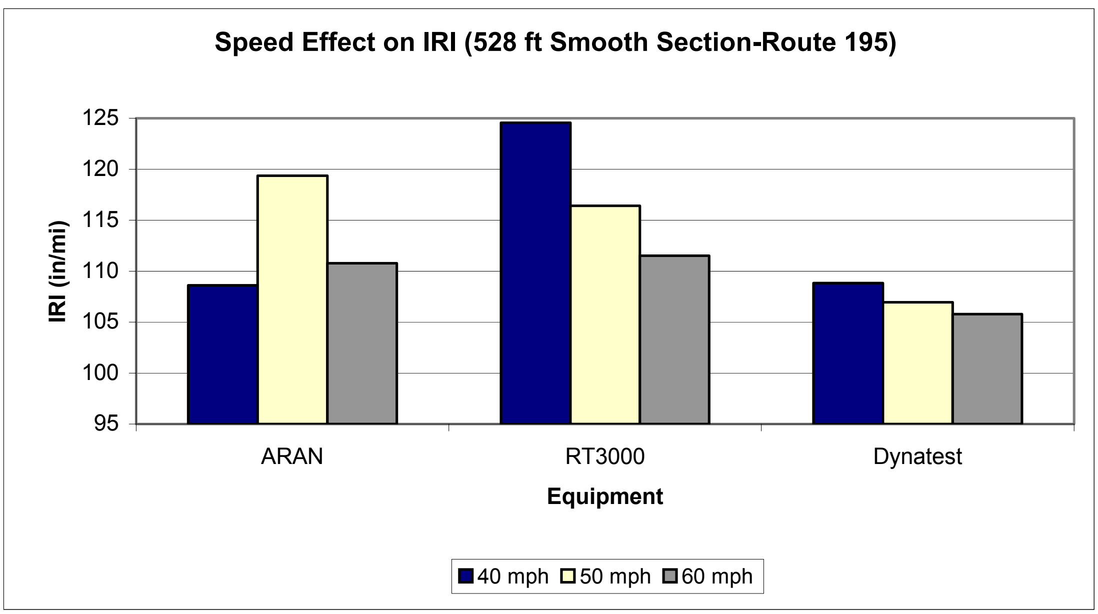


Figure 36. Speed Effect on IRI (528-ft Smooth Section – Route 195).

Filtering Effects

The effect of filtering was investigated using RoadRuf. Moving average filters with different base lengths, combinations of low pass and high pass filter options, were applied to the R&L, WP and RT3000 raw unfiltered profiles. Profiles from ARAN and Dynatest were not considered in this exercise because they were already filtered during the data collection. The following filter combinations were investigated:

Low pass (LP) filters of 1, 2 and 3 ft

High pass (HP) filters of 100, 200, and 300 ft

Band filters (BF) of 1-300, 2-300, and 3-300

Low pass filters remove wavelengths less than the specified length while high pass filters remove wavelength greater than the specified length. Band filters are a combination of both LP and HP filters.

Analysis using all of the above filter settings was done for only one section (528-ft) in each roughness class. Samples of the results for a very smooth section (Route 55), smooth section (Route 195) and relatively rough section (Route 18) are shown in figures 37 to 45. However all sections were filtered using 300 HP, results of which are presented in Appendix B.

As can be seen, changes in HP filters do not significantly affect the R&L profiles. The presented figures suggest that the amplitude of the RT3000 profiles decreases significantly when the high-pass cutoff length is reduced from 300 to 200 ft. Profiles after band filtering are also similar to those from the corresponding HP filtering.

The general purpose of filtering profiles before determination of ride statistics or roughness evaluation is to remove wavelengths that are considered unimportant in the evaluation. In general, this is usually accomplished by high-pass or band filtering and cannot be achieved by LP filtering alone.

The results of LP filtering using the specified cutoff lengths are shown in figures 37a to 45a. It should be noted that LP filter profiles still contain the “grade” or slope of the road because of the short cutoff length used. The LP filtered profiles from R&L and WP do not always compare well with those from high-speed profilers such as ICC RT3000, as shown in figure 43a to 45a, because of the method in which they are collected. For the R&L and WP surveys, elevation measurements are referenced to that of the starting point, while in the case of the RT3000, the inertial reference (reference elevation) is set by accelerometers. This reference could change from one measurement to another depending on the smoothness of the tested pavement.

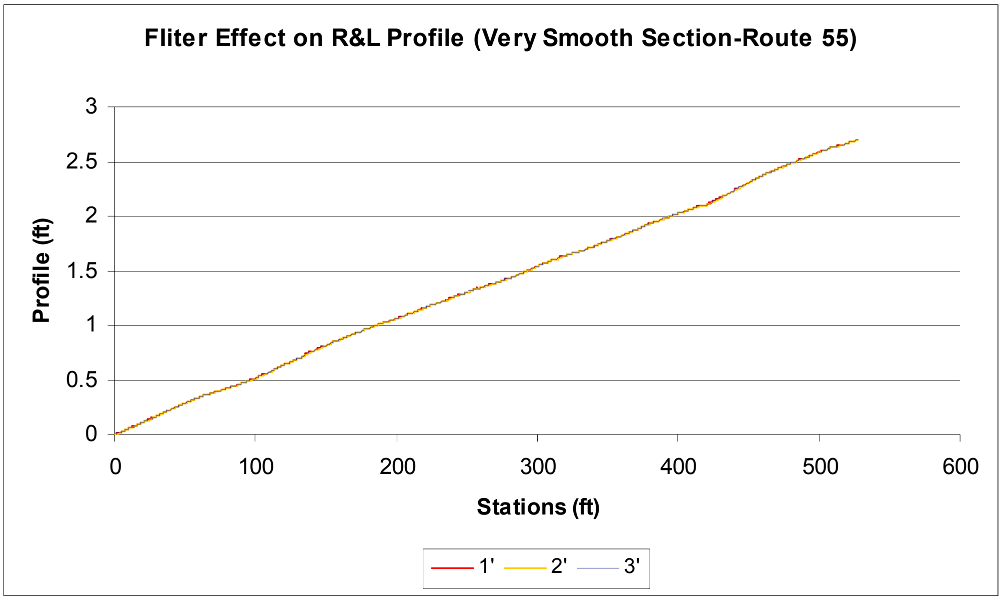


Figure 37a. Filter Effect on R&L Profile (Very Smooth Section - Route 55).

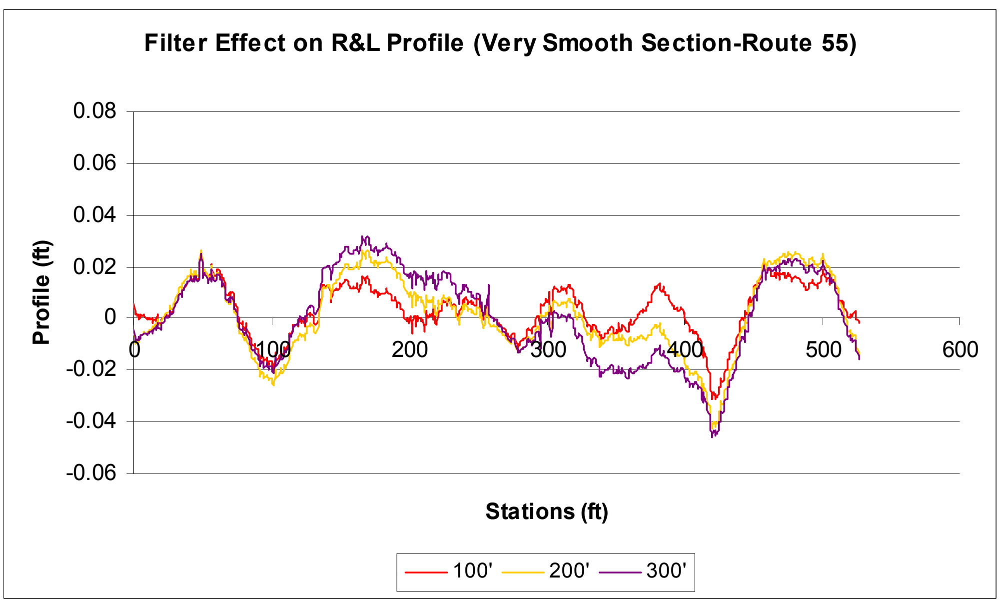


Figure 37b. Filter Effect on R&L Profile (Very Smooth Section - Route 55).

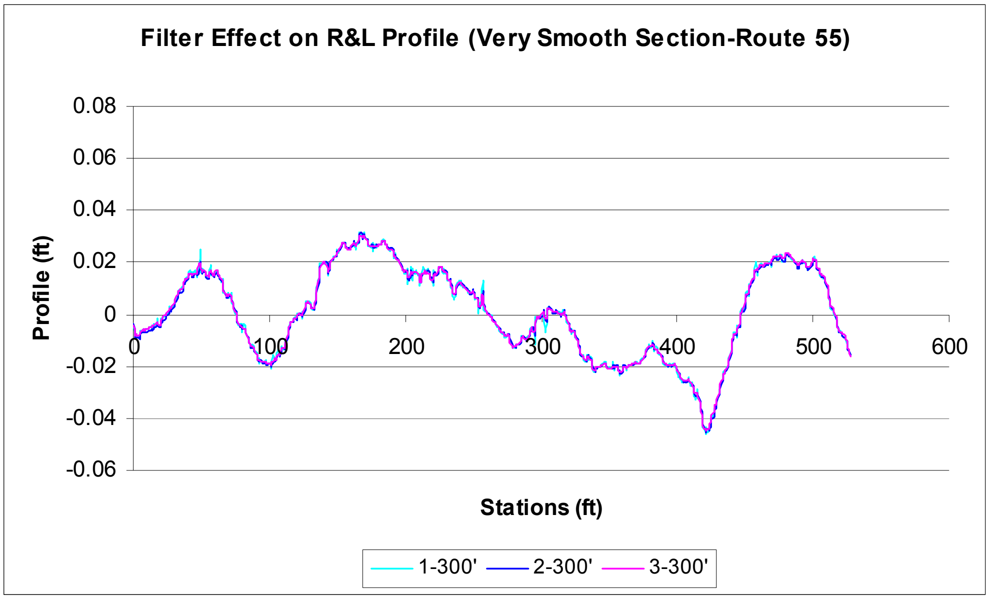


Figure 37c. Filter Effect on R&L Profile (Very Smooth Section - Route 55).

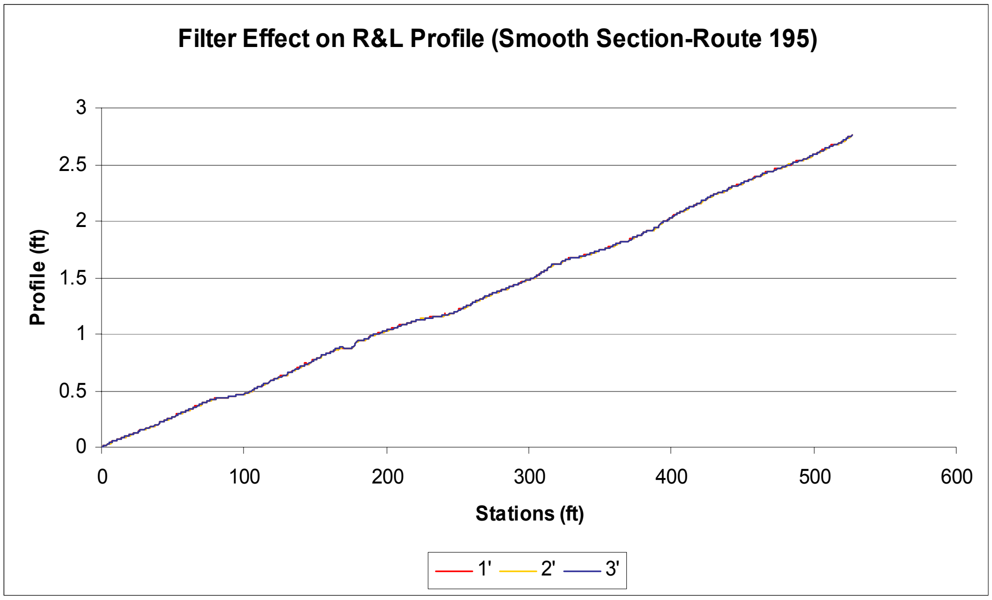


Figure 38a. Filter Effect on R&L Profile (Smooth Section - Route 195).

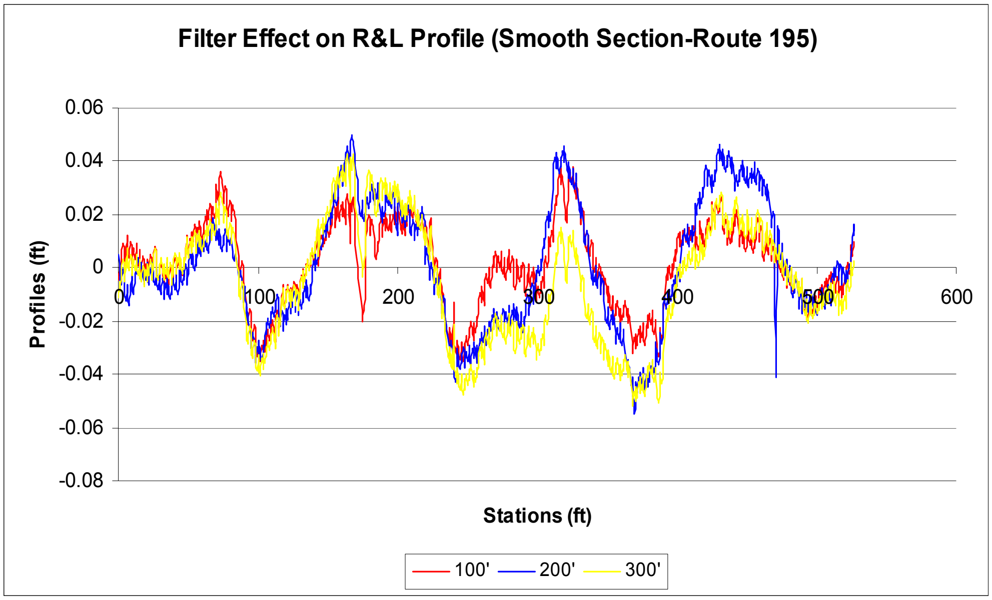


Figure 38b. Filter Effect on R&L Profile (Smooth Section - Route 195).

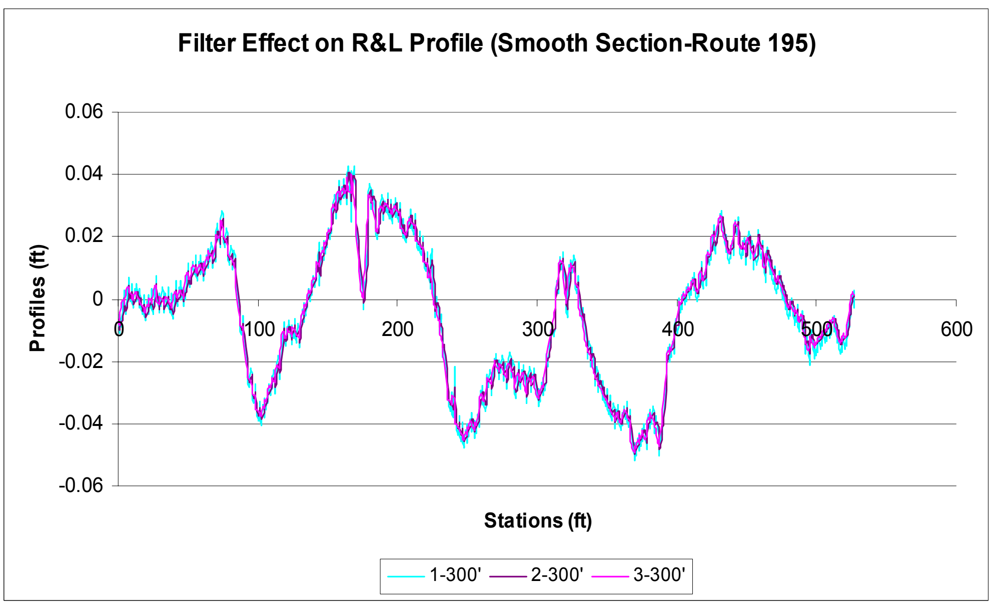


Figure 38c. Filter Effect on R&L Profile (Smooth Section - Route 195).

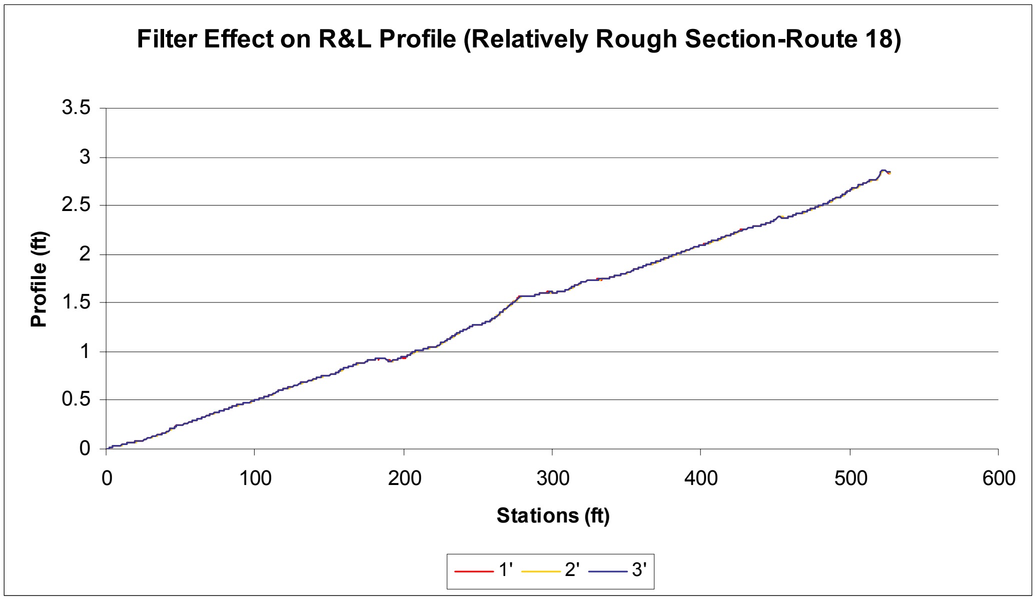


Figure 39a. Filter Effect on R&L Profile (Relatively Rough Section - Route 18).

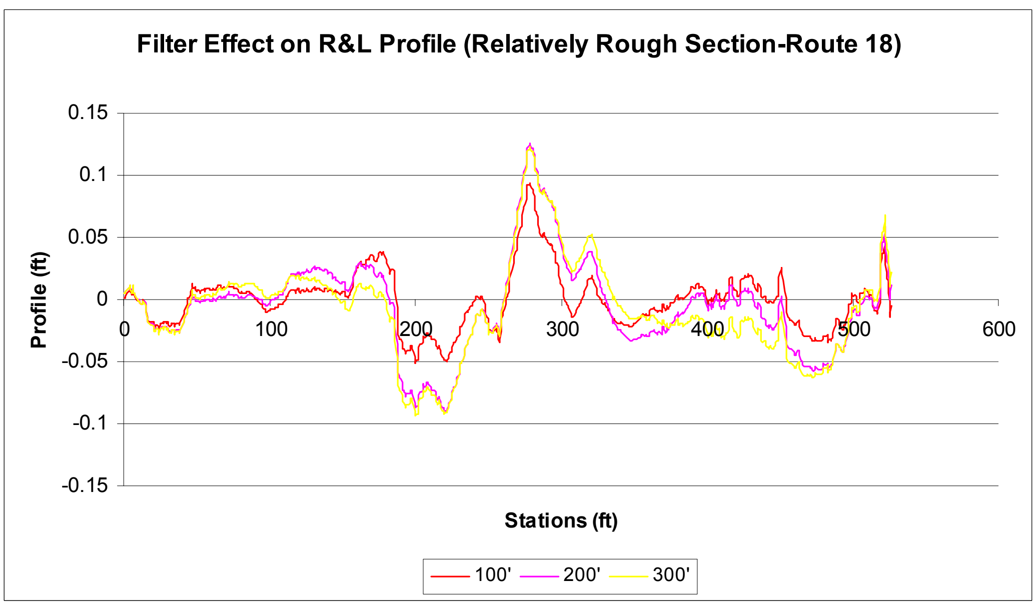


Figure 39b. Filter Effect on R&L Profile (Relatively Rough Section - Route 18).

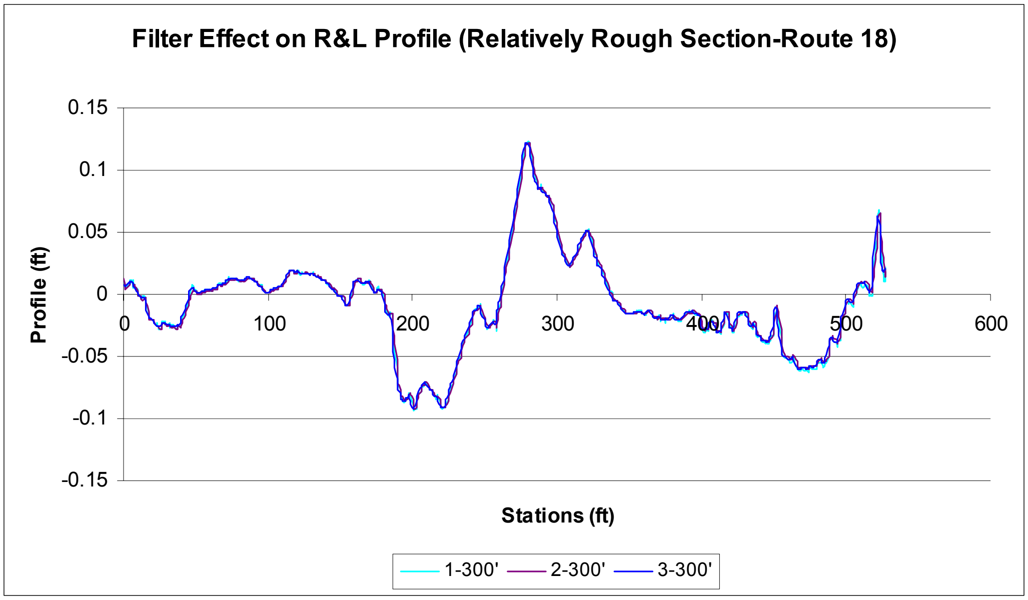


Figure 39c. Filter Effect on R&L Profile (Relatively Rough Section - Route 18).

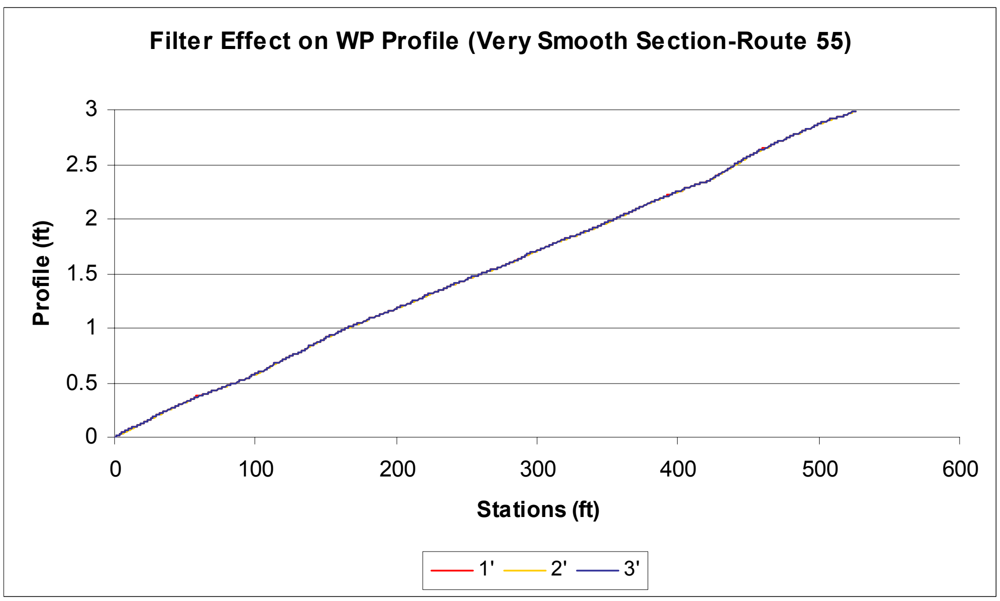


Figure 40a. Filter Effect on WP Profile (Very Smooth Section - Route 55).

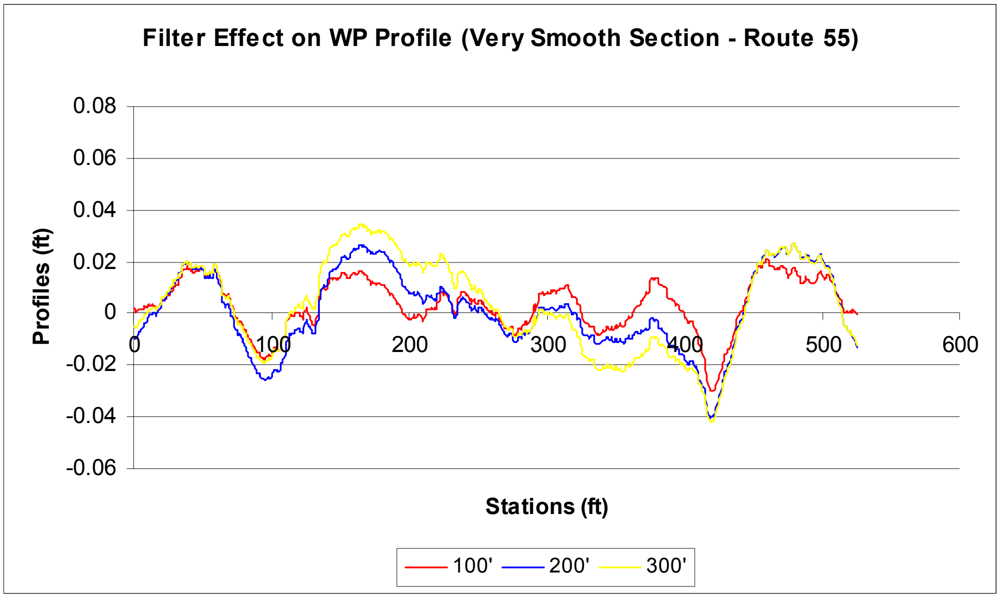


Figure 40b. Filter Effect on WP Profile (Very Smooth Section - Route 55).

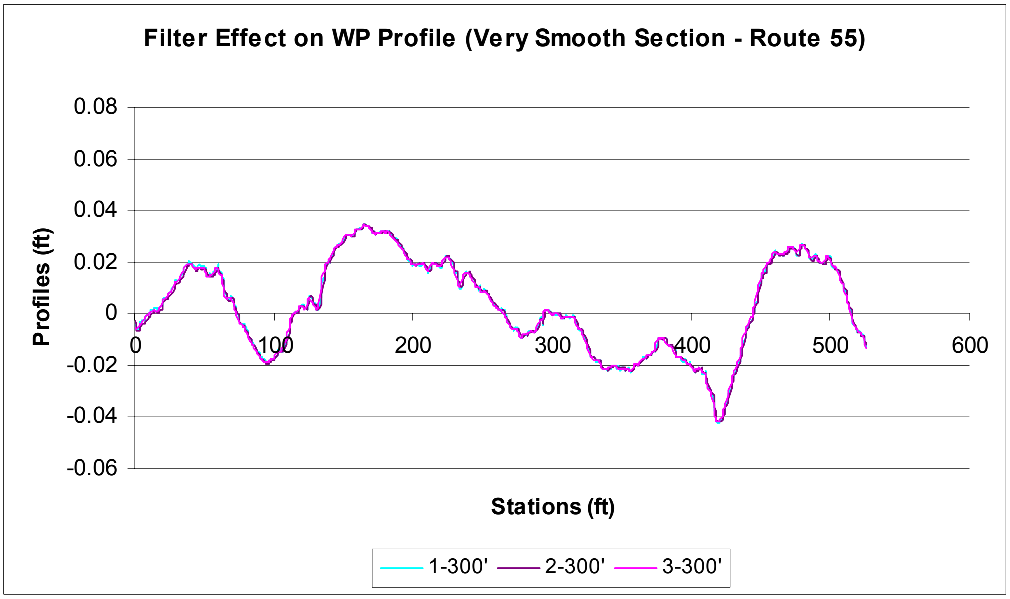


Figure 40c. Filter Effect on WP Profile (Very Smooth Section - Route 55).

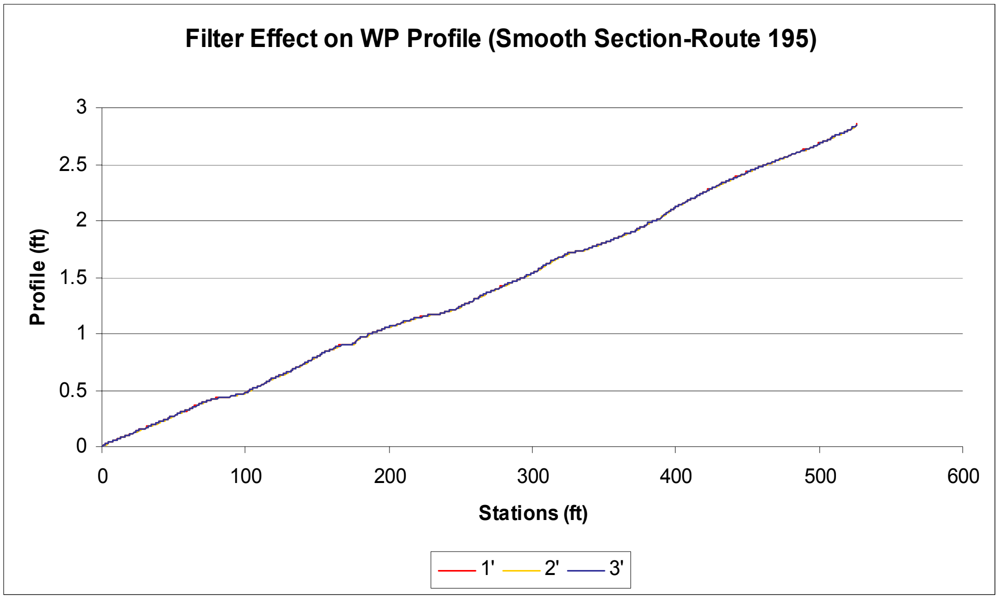


Figure 41a. Filter Effect on WP Profile (Smooth Section - Route 195).

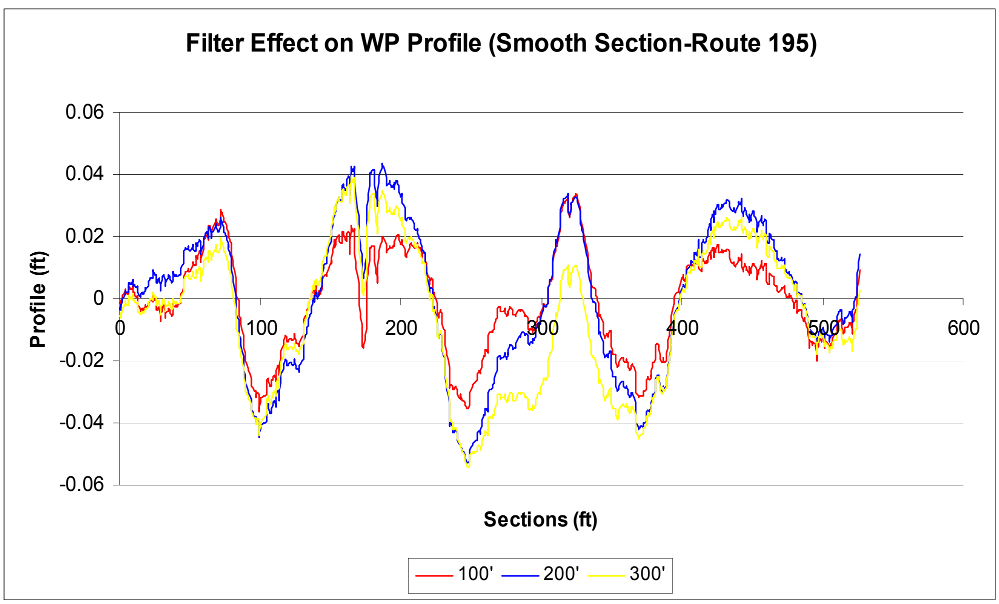


Figure 41b. Filter Effect on WP Profile (Smooth Section - Route 195).

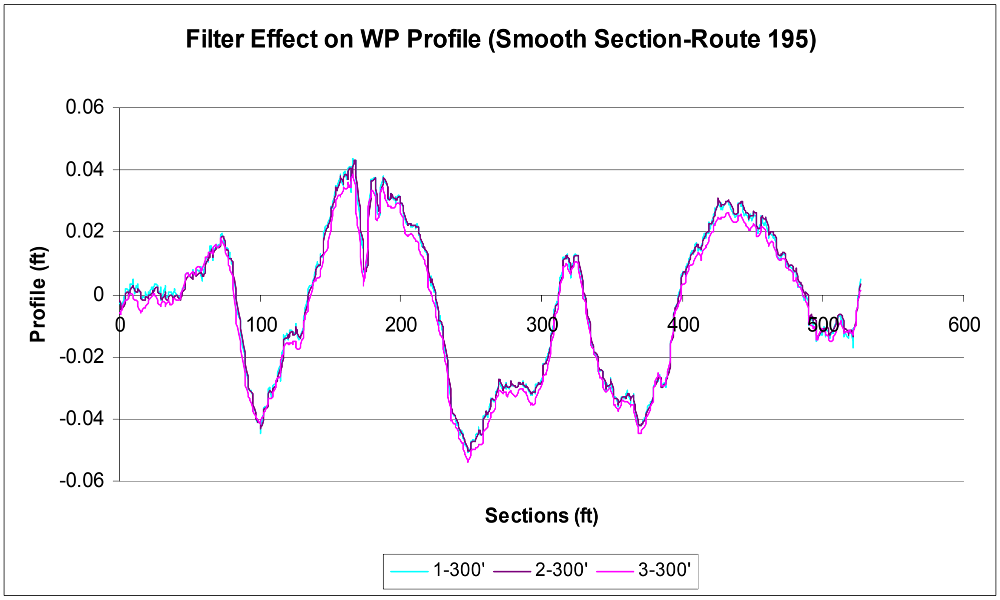


Figure 41c. Filter Effect on WP Profile (Smooth Section - Route 195).

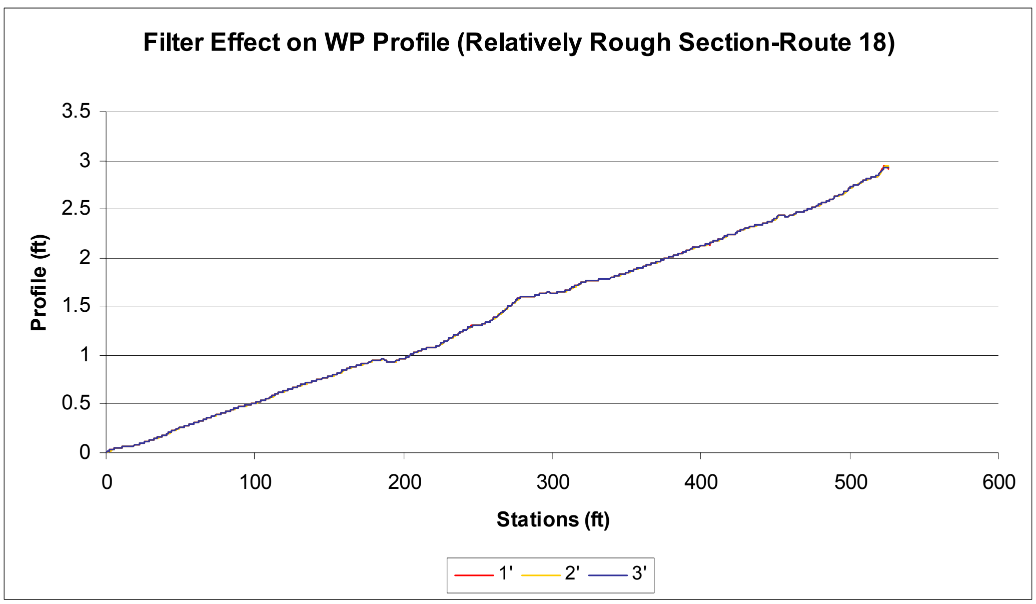


Figure 42a. Filter Effect on WP Profile (Relatively Rough Section - Route 18).

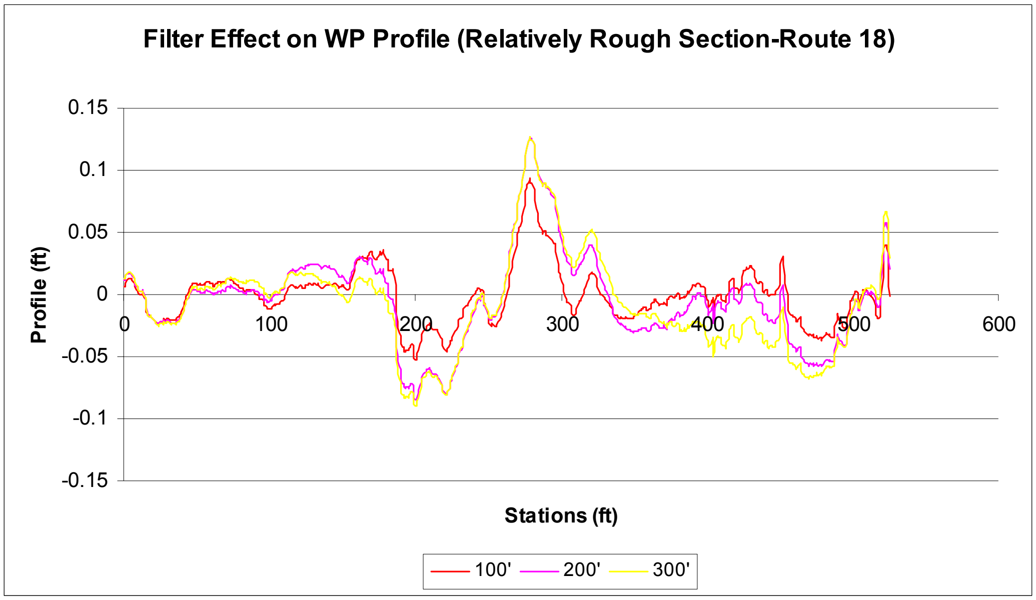


Figure 42b. Filter Effect on WP Profile (Relatively Rough Section - Route 18).

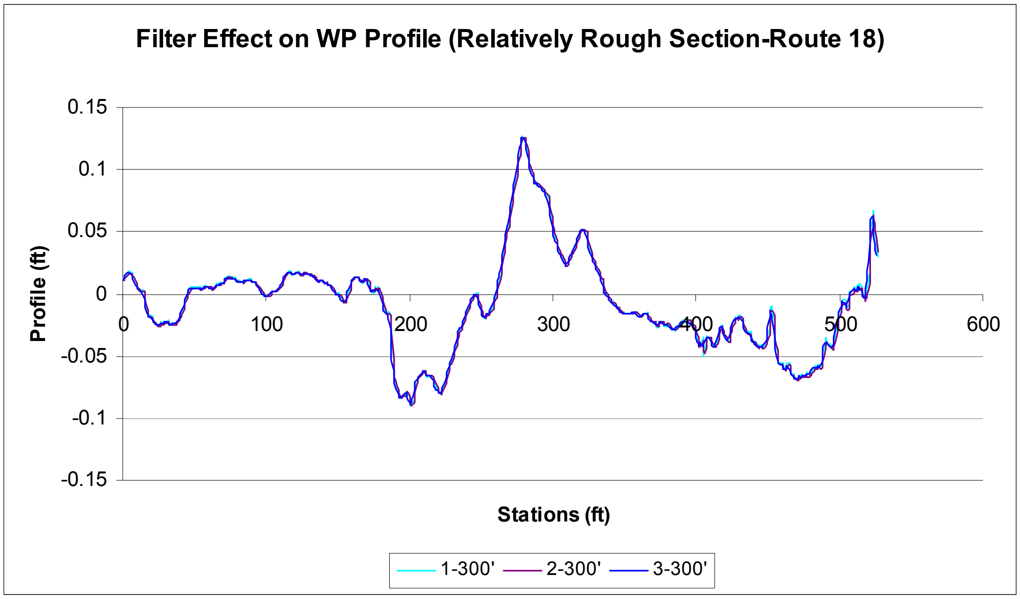


Figure 42c. Filter Effect on WP Profile (Relatively Rough Section - Route 18).

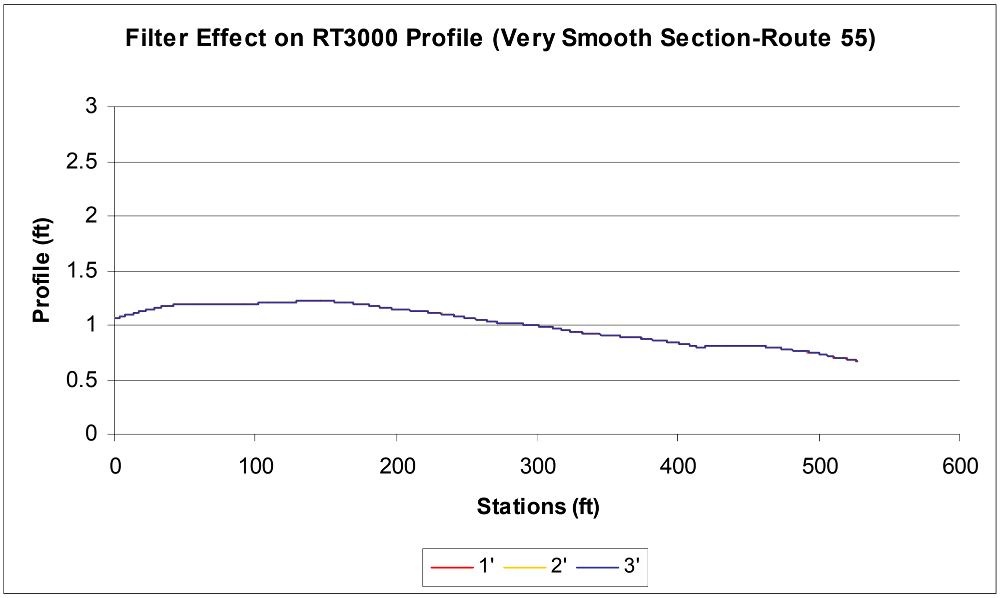


Figure 43a. Filter Effect on RT3000 Profile (Very Smooth Section - Route 55).

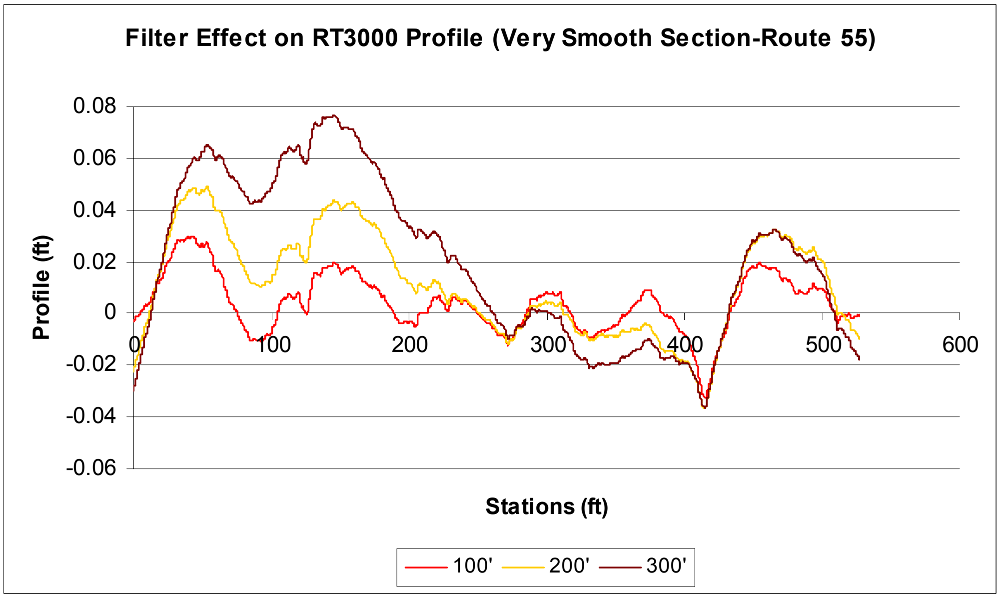


Figure 43b. Filter Effect on RT3000 Profile (Very Smooth Section - Route 55).

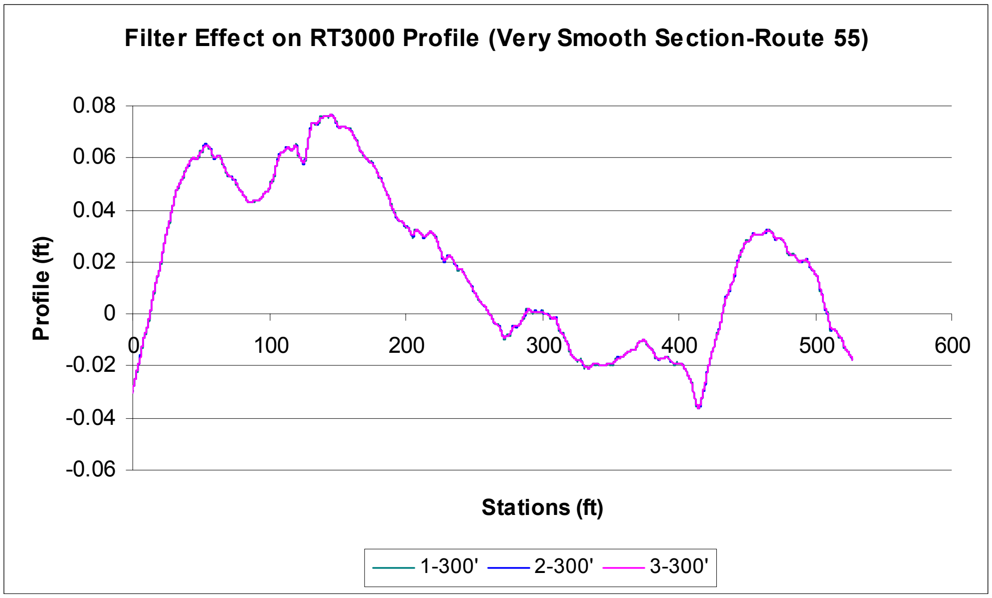


Figure 43c. Filter Effect on RT3000 Profile (Very Smooth Section - Route 55).

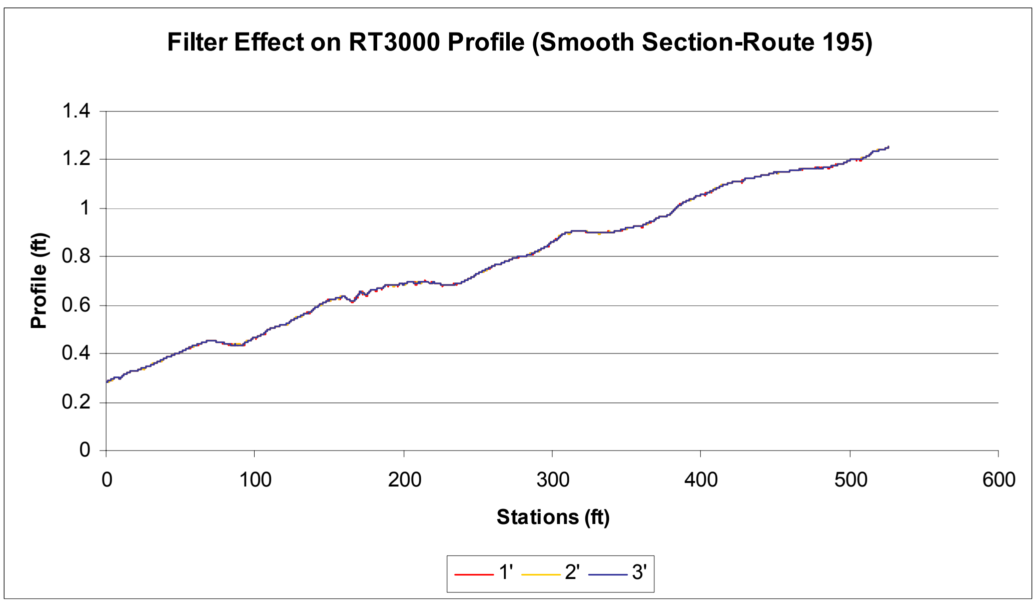


Figure 44a. Filter Effect on RT3000 Profile (Smooth Section - Route 195).

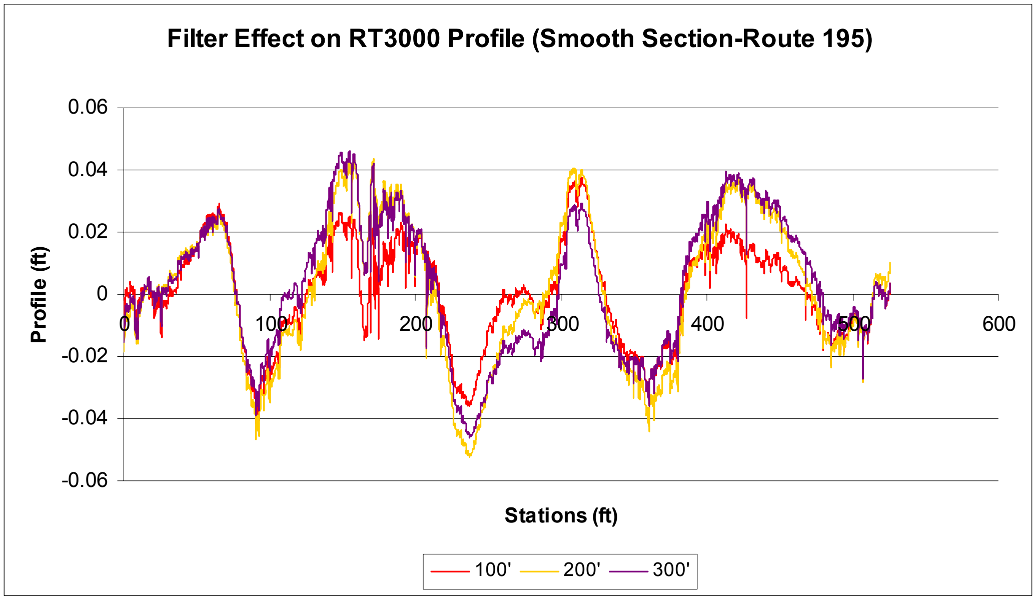


Figure 44b. Filter Effect on RT3000 Profile (Smooth Section - Route 195).

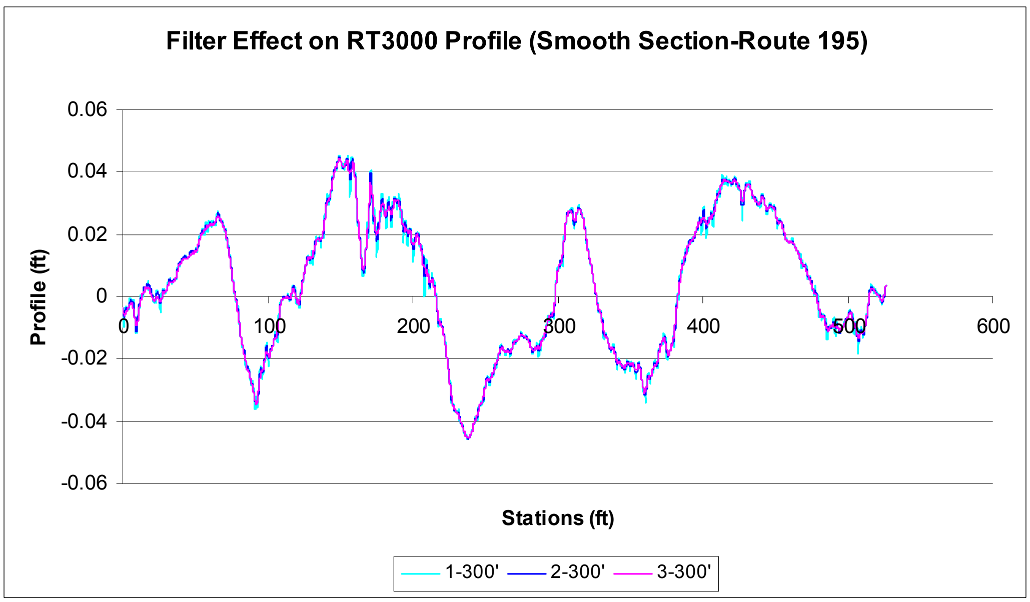


Figure 44c. Filter Effect on RT3000 Profile (Smooth Section - Route 195).

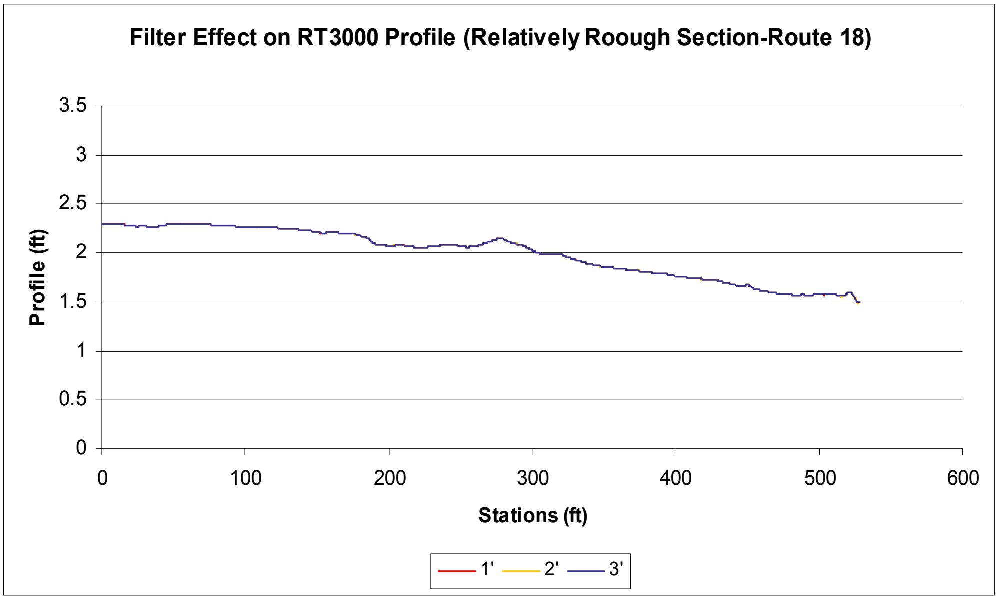


Figure 45a. Filter Effect on RT3000 Profile (Relatively Rough Section - Route 18).

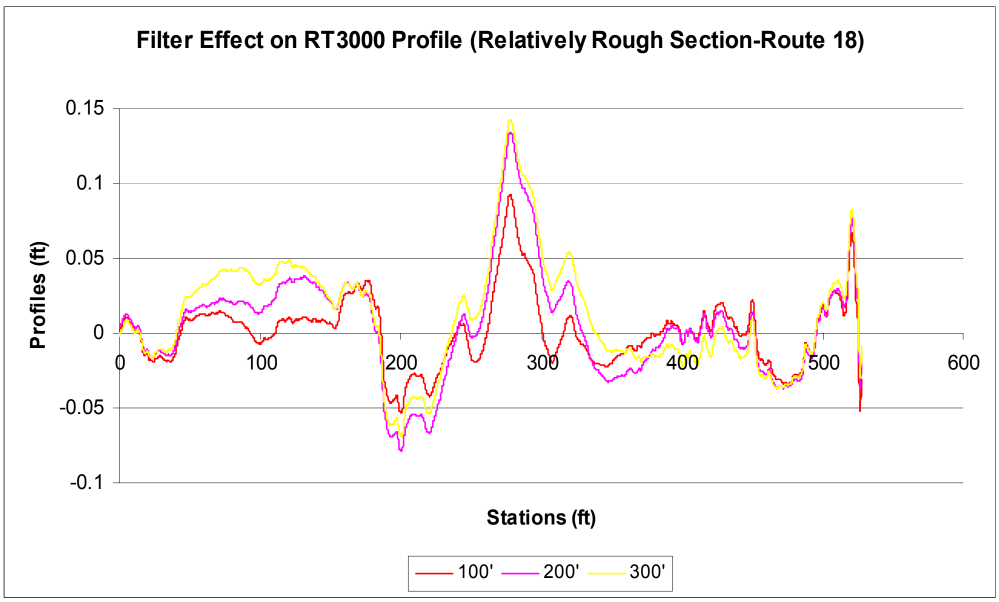


Figure 45b. Filter Effect on RT3000 Profile (Relatively Rough Section - Route 18).

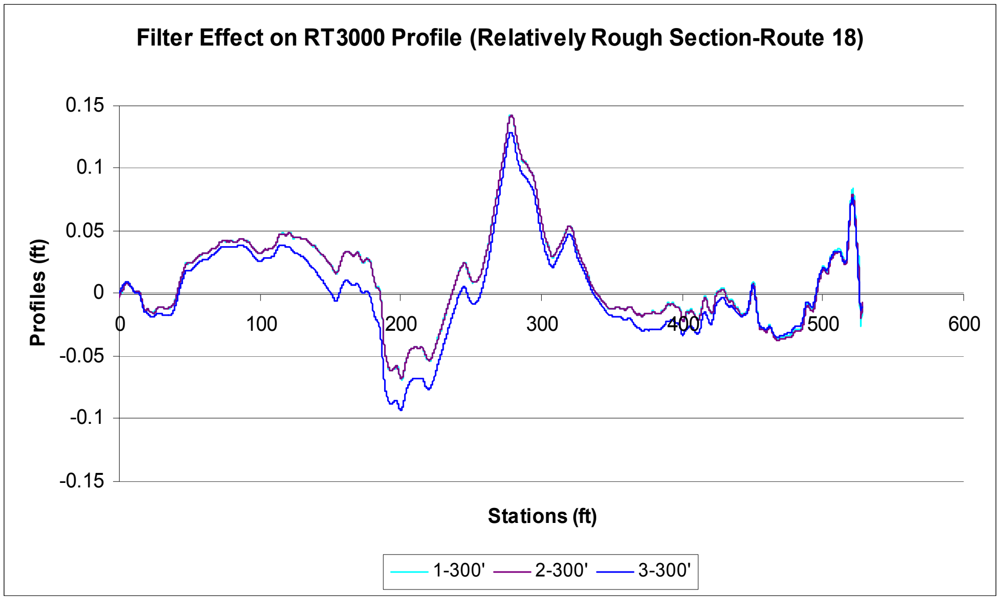


Figure 45c. Filter Effect on RT3000 Profile (Relatively Rough Section - Route 18).

The effect of filtering on the computed IRI varies from one device to another, with R&L being the least affected. The differences between the unfiltered IRI and those after band filtering are more pronounced than that between unfiltered IRI and those after high pass filtering alone.

The results from LP filtering of the RT3000 profiles for the first 3 sub-sections are unreasonable, as can be seen in table 6; while the results for the rest of the sub-sections (as well as results from HP and band filtering) are comparable to those of the other devices. The manufacturer, ICC could not provide any conclusive comments on this at the time of preparing of this report, but promised to investigate the issue and report to Stantec later.

Neglecting the results from LP filtering and excluding the first sub-section, this difference can be as high as 55 in/mi for the RT3000, 25 in/mi for WP and 26 in/mi for R&L. The main reason for excluding the first sub-section (52.8-ft) is that the IRI filter initialization distance is set at 36-ft in RoadRuf. Therefore, this initialization distance influences results for the first sub-section. The maximum differences between the IRI calculated from unfiltered and filtered profiles from the 52.8-ft sub-sections (one section per roughness class) are shown in table 6 and figures 46 to 54.

Table 6. Maximum Difference in IRI [in/mi] between Unfiltered and Filtered Profiles for 52.8-ft Sub-section.

	Low Pass Filters (ft)			High Pass Filter (ft)			Band Filters-Cutoff Length (ft)		
SECTION 1 - Smooth, IRI (in/mi)									
	1	**2**	**3**	**100**	**200**	**300**	**1-300**	**2-300**	**3-300**
R&L	3.42	13.77	25.04	4.99	4.15	5.5	3.68	14.64	24.74
WP	0.32	8.87	19.21	6.16	10.45	4.63	1.47	9.17	20.76
RT3000	32.48*	28.92*	58.33*	7.64	6.16	5.87	5.39	27.82	55.32
SECTION 11 - Very Smooth, IRI (in/mi)									
R&L	2.28	6.01	13.34	4.59	2.29	2.59	2.59	5.85	13.13
WP	2.74	4.7	6.87	3.78	3.13	2.8	2.47	4.93	6.9
RT3000	126*	126*	126*	2.44	1.97	1.67	126*	1.61	9.27
SECTION 23 - Relatively Rough, IRI (in/mi) (Caution when reviewing Route 18 results.)									
R&L	5.84	12.51	29.57	12.48	7.63	8.47	7.94	12.26	26.3
WP	4.06	26.65	28.05	13.64	5.55	7.16	5.05	26.38	25.4
RT3000	337*	338*	338*	10.26	5.93	3.83	9.54	27.08	49.33

*reported to ICC

The differences between the results from unfiltered and filtered profiles change depending on the roughness class, as shown in table 6. The trend of each equipment is not consistent and the differences can be significant. However, the 3-ft low pass filter and the band 3-300 filter have the most significant impact.

The IRI for the entire 528-ft section (except for RT3000 LP filtering) is less affected by filtering as shown in table 7. Band filtering however, resulted in differences as high as 21 in/mi for the RT3000, 19.5 in/mi for R&L and 11 in/mi for WP. (Discrepancy for low pass filter results from RT3000 was reported to ICC and the issue was not resolved by the conclusion of this study.)

The demonstrated impact of filtering on IRI, in general and more specifically for the high-speed profiler, such as RT3000, reinforces the needs for standard profile filtering specifications. For network inventory purposes, this issue may not be relevant however, for pavement ride quality specifications, even a 5 percent difference may result in either a penalty or a bonus. The need to establish standardized filtering criteria for all profiling devices cannot be overstated.

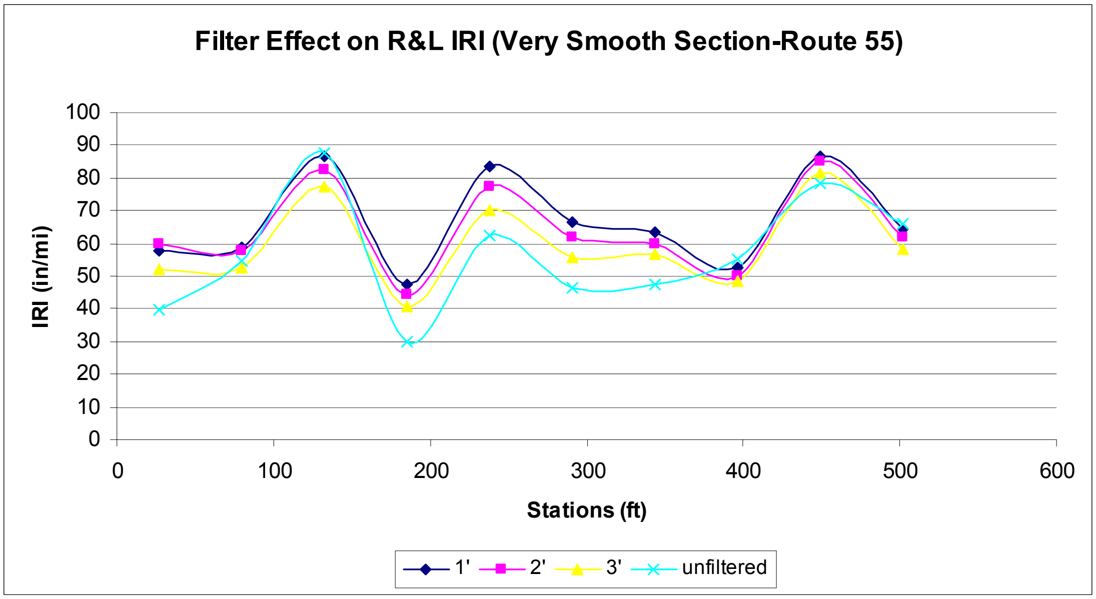


Figure 46a. Filter Effect on R&L IRI (Very Smooth Section - Route 55).

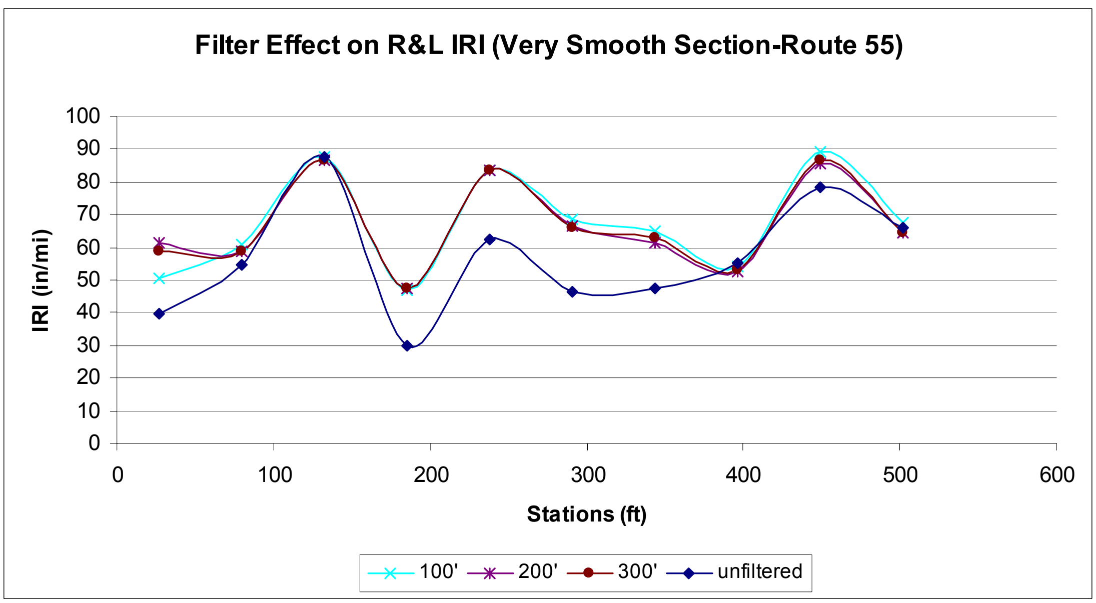


Figure 46b. Filter Effect on R&L IRI (Very Smooth Section - Route 55).

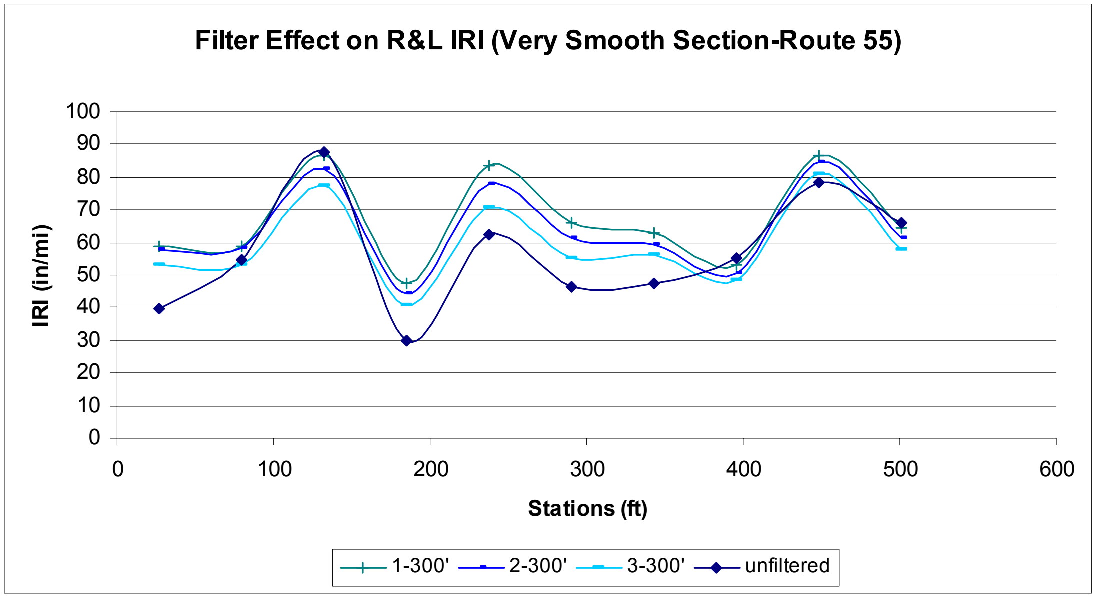


Figure 46c. Filter Effect on R&L IRI (Very Smooth Section - Route 55).

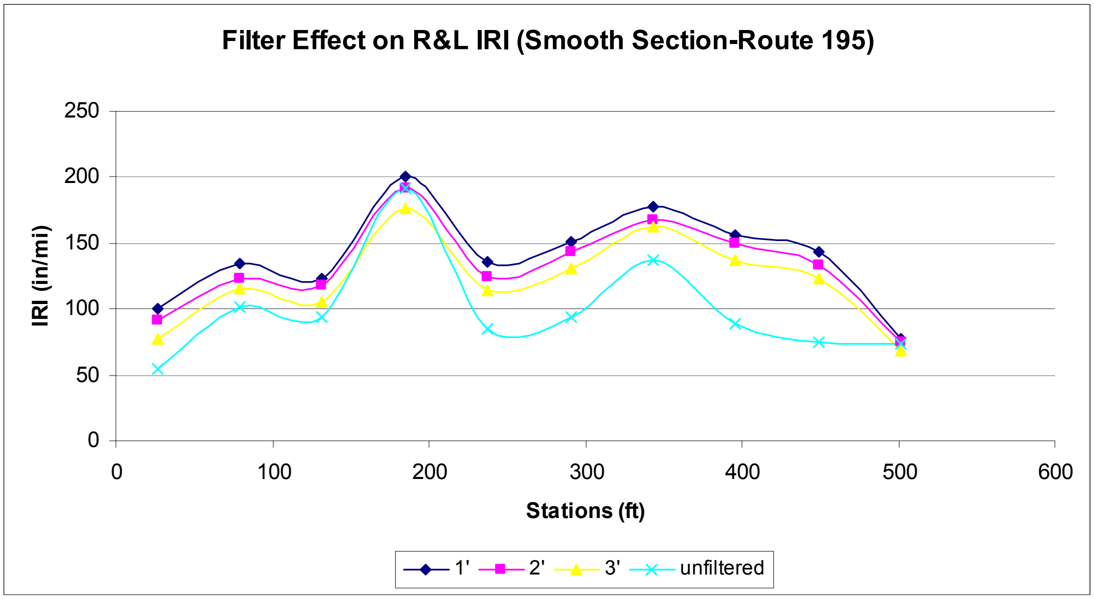


Figure 47a. Filter Effect on R&L IRI (Smooth Section - Route 195).

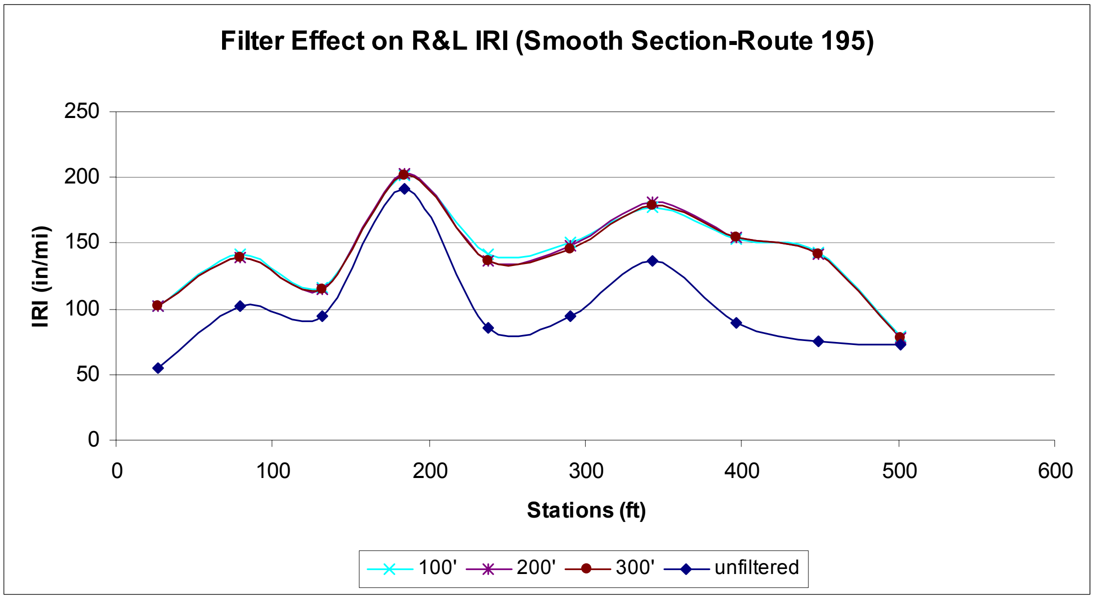


Figure 47b. Filter Effect on R&L IRI (Smooth Section - Route 195).

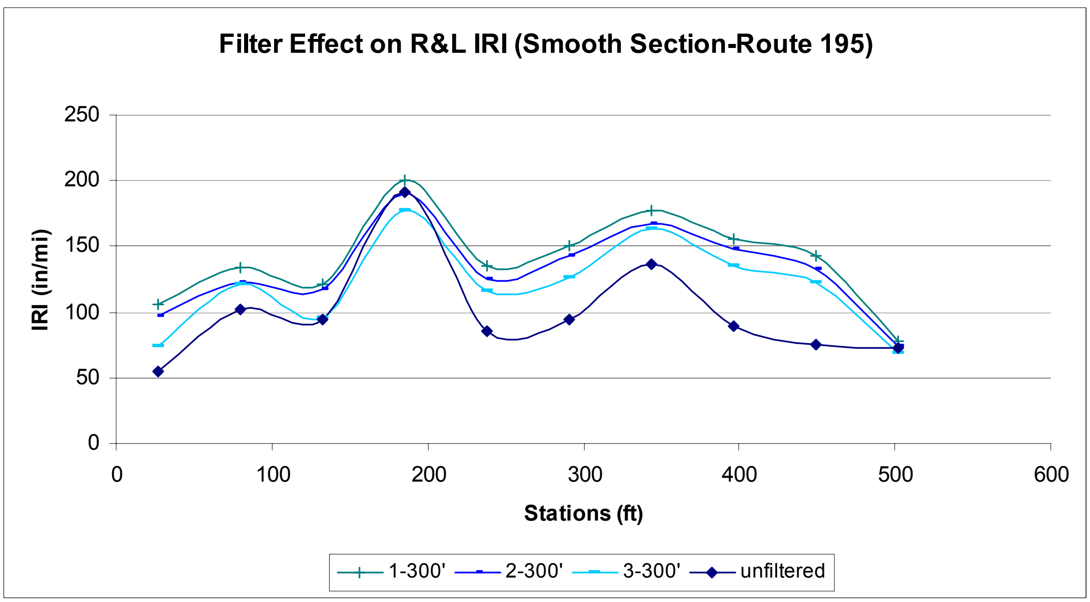


Figure 47c. Filter Effect on R&L IRI (Smooth Section - Route 195).

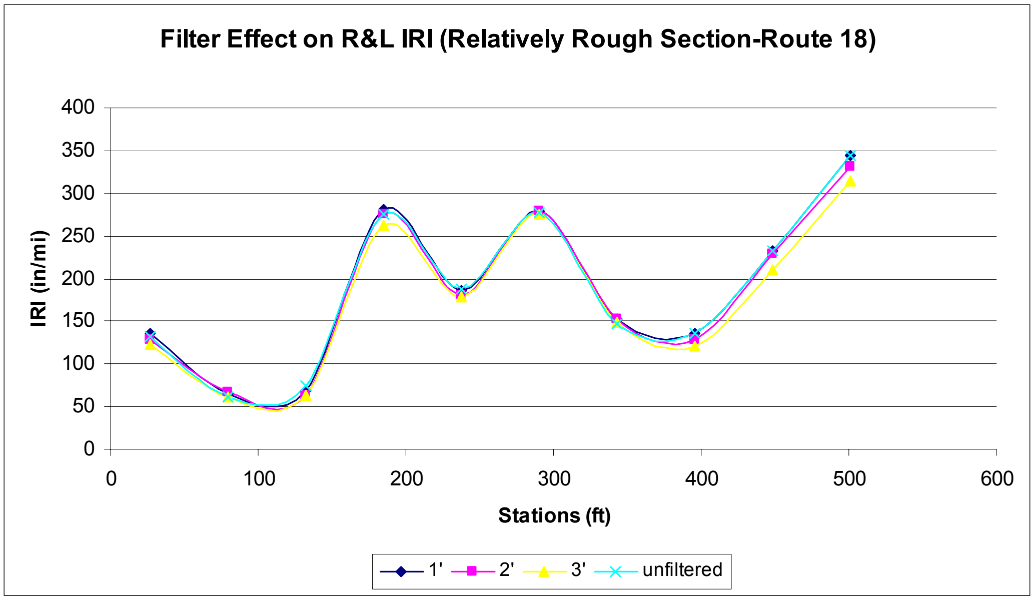


Figure 48a. Filter Effect on R&L IRI (Relatively Rough Section - Route 18).

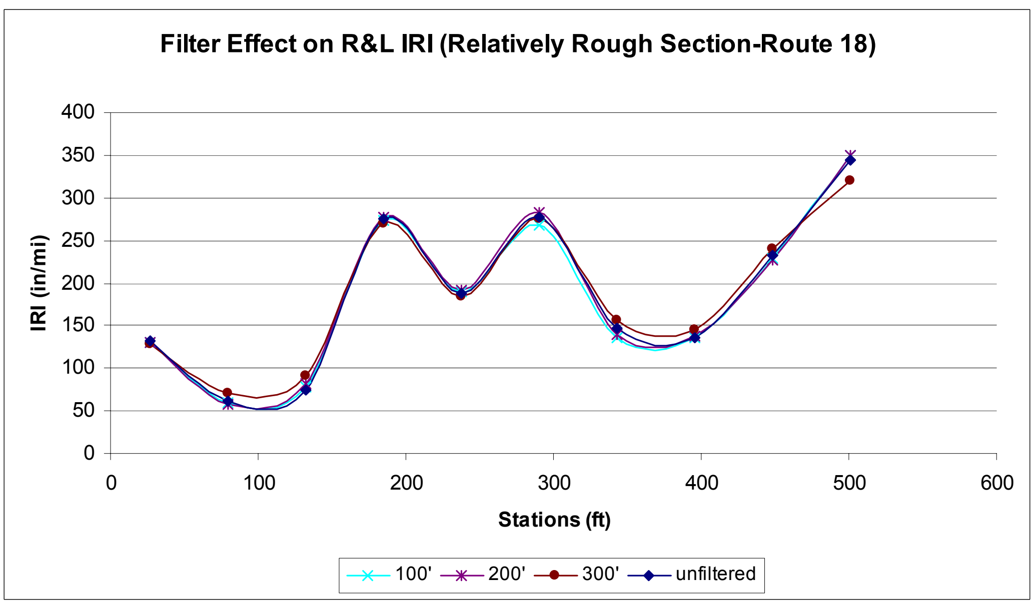


Figure 48b. Filter Effect on R&L IRI (Relatively Rough Section - Route 18).

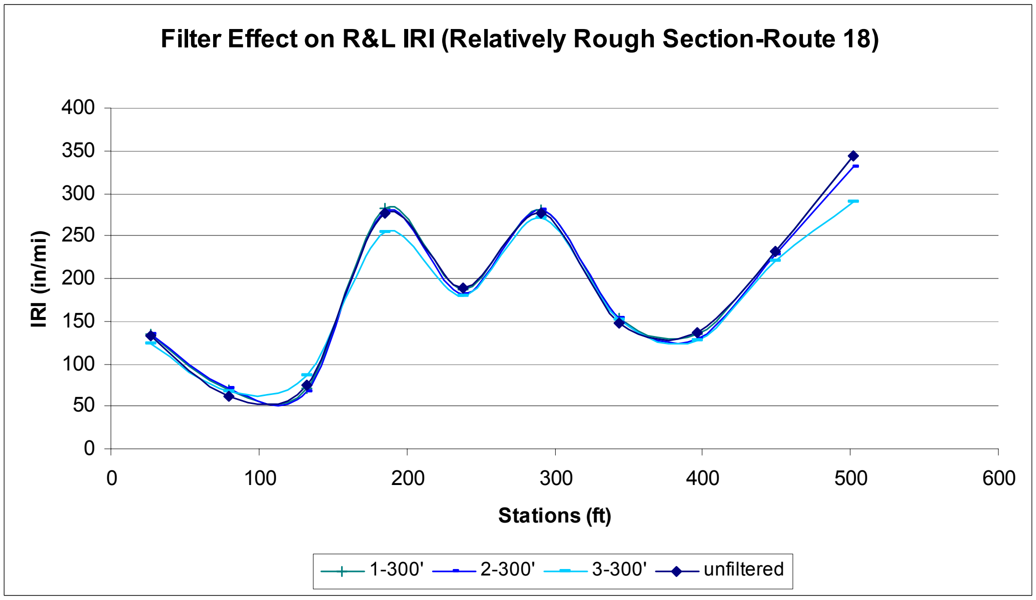


Figure 48c. Filter Effect on R&L IRI (Relatively Rough Section - Route 18).

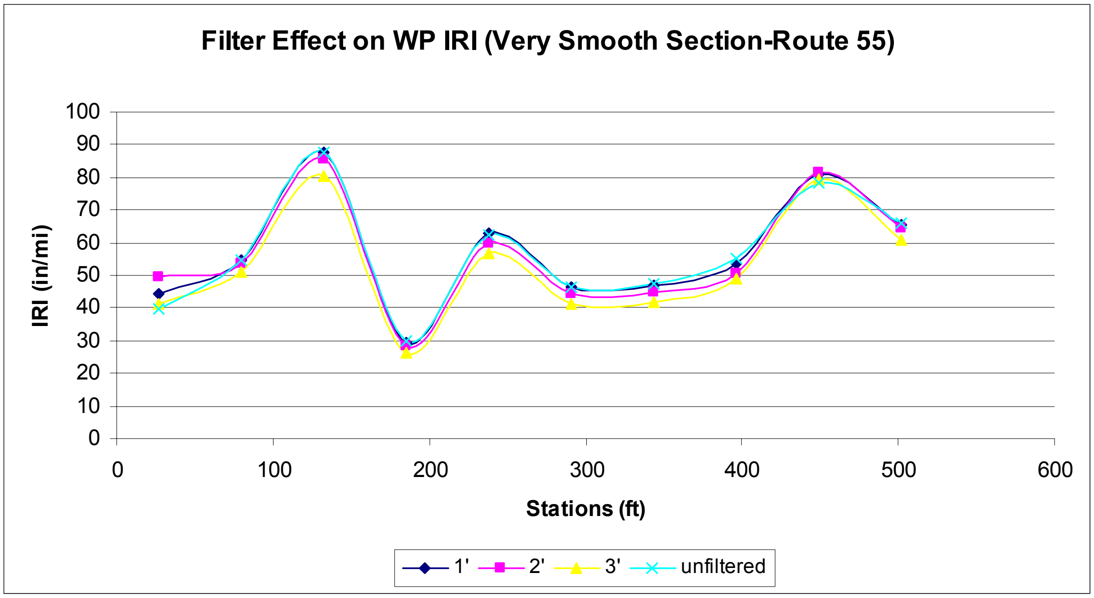


Figure 49a. Filter Effect on WP IRI (Very Smooth Section - Route 55).

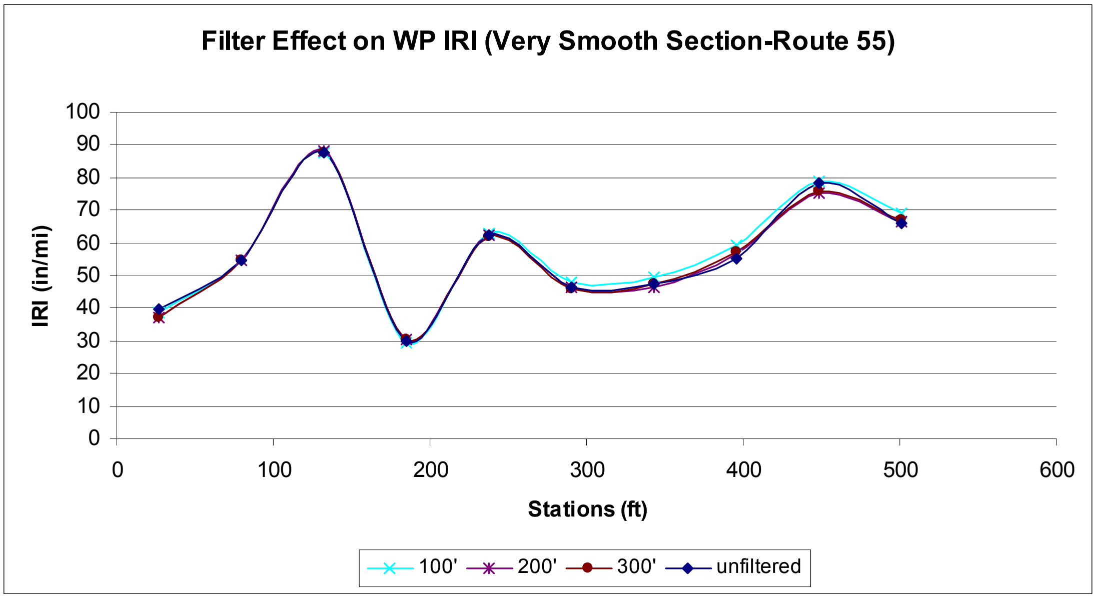


Figure 49b. Filter Effect on WP IRI (Very Smooth Section - Route 55).

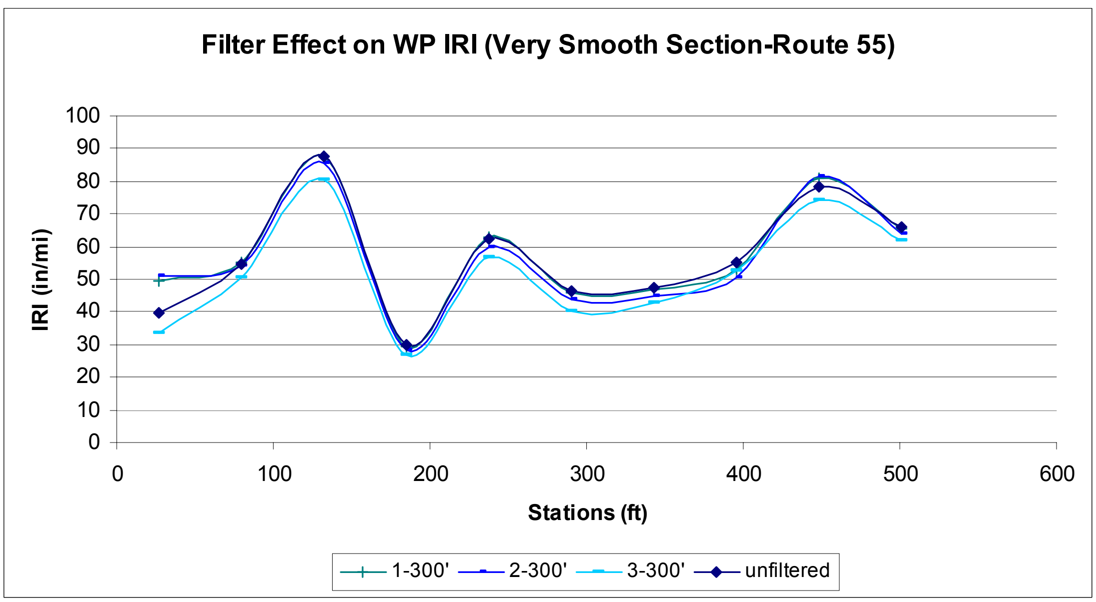


Figure 49c. Filter Effect on WP IRI (Very Smooth Section - Route 55).

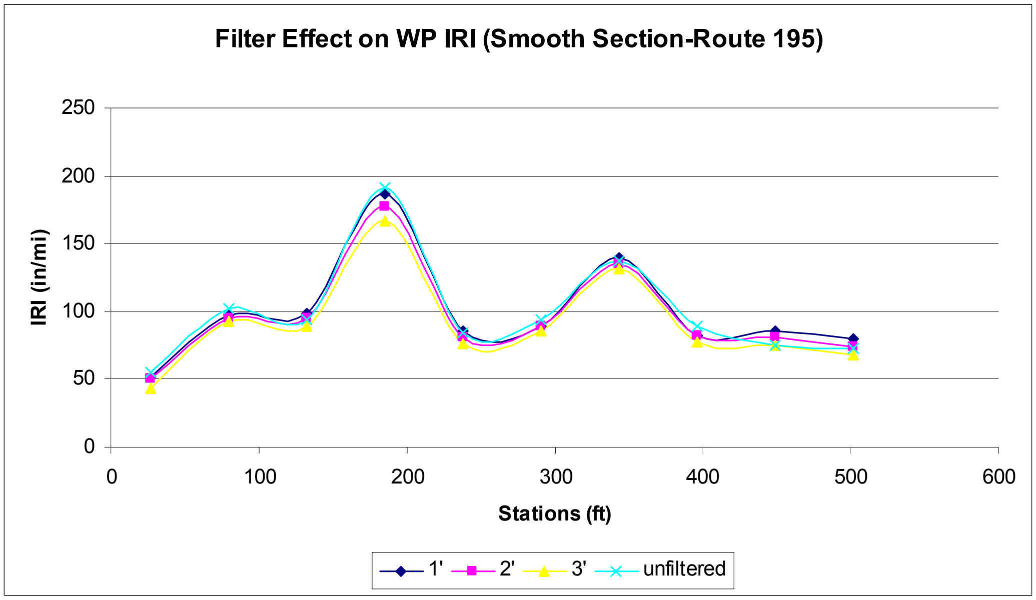


Figure 50a. Filter Effect on WP IRI (Smooth Section - Route 195).

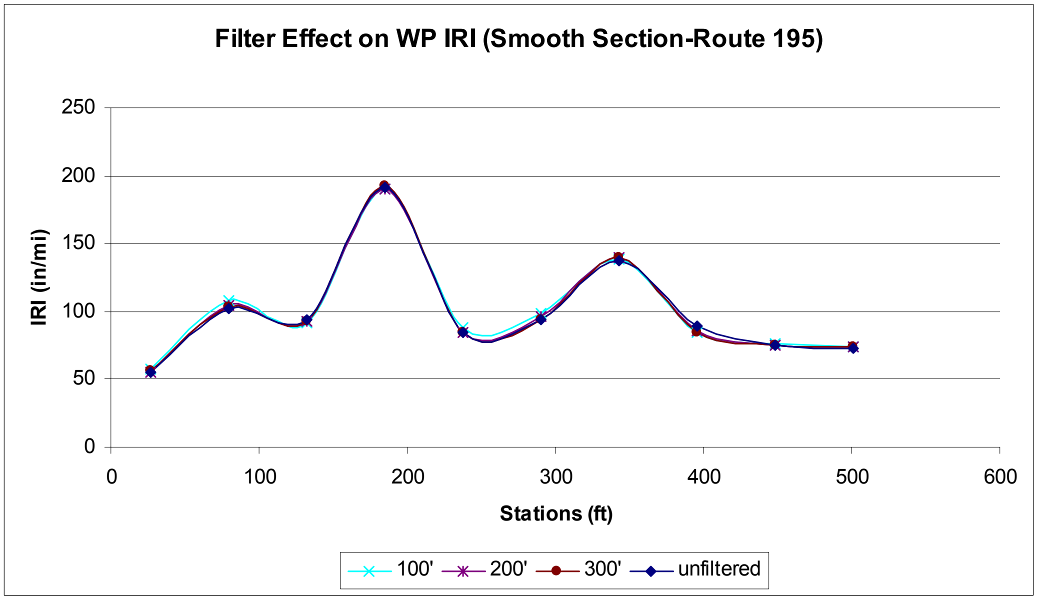


Figure 50b. Filter Effect on WP IRI (Smooth Section - Route 195).

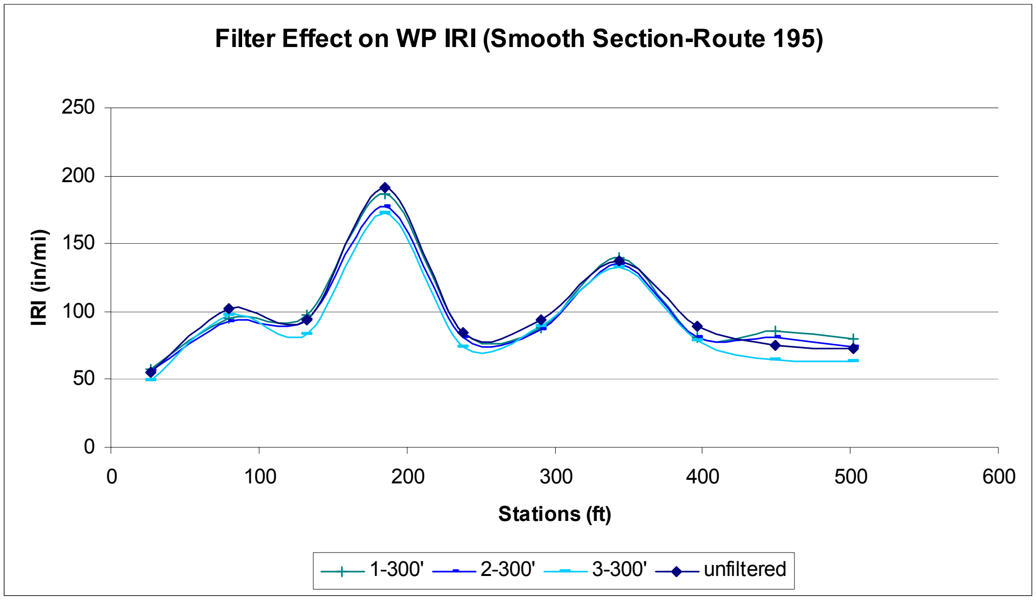


Figure 50c. Filter Effect on WP IRI (Smooth Section - Route 195).

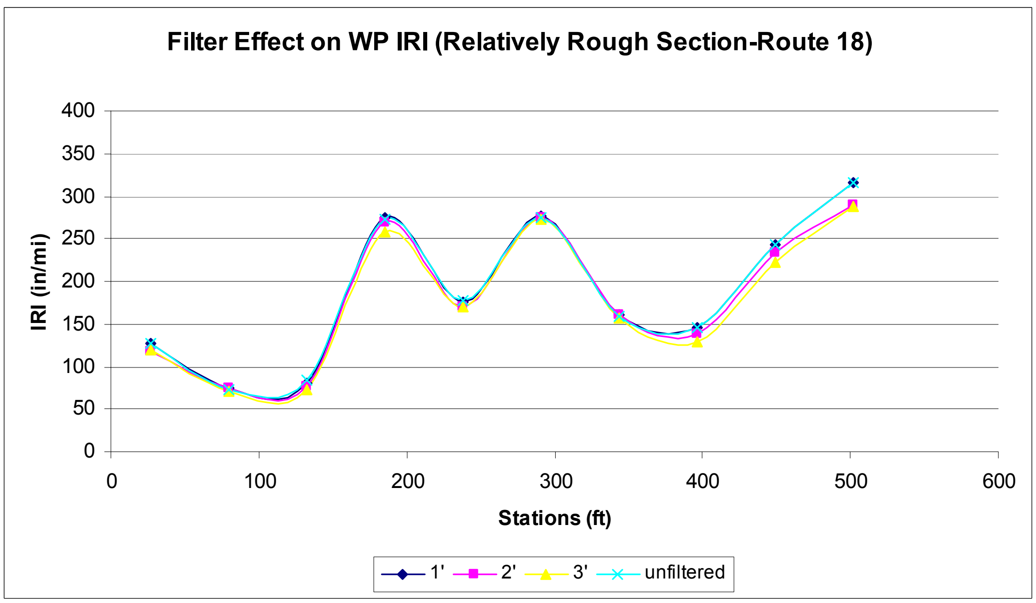


Figure 51a. Filter Effect on WP IRI (Relatively Rough Section - Route 18).

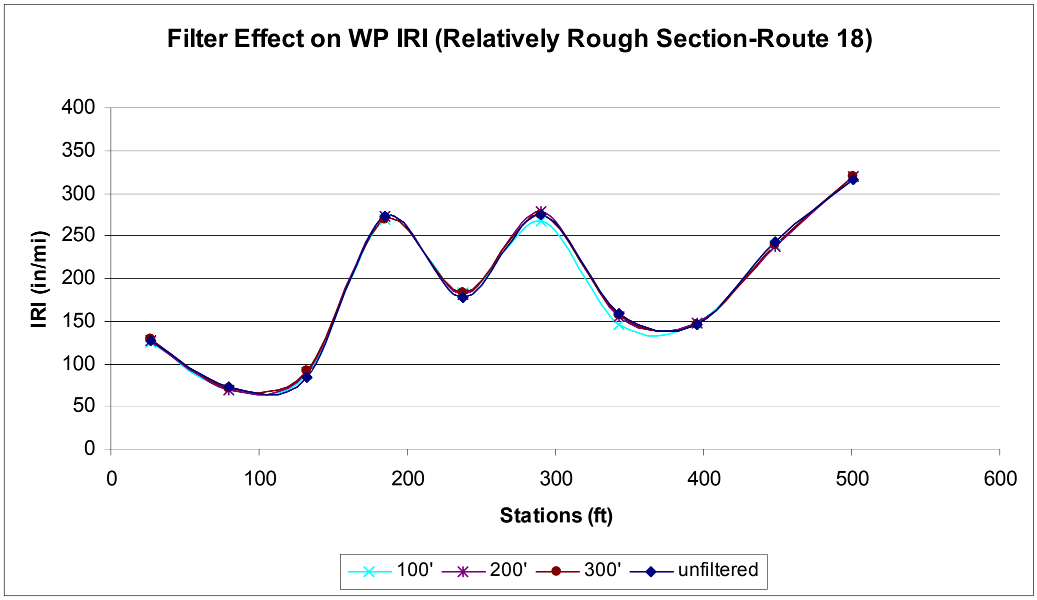


Figure 51b: Filter Effect on WP IRI (Relatively Rough Section - Route 18)

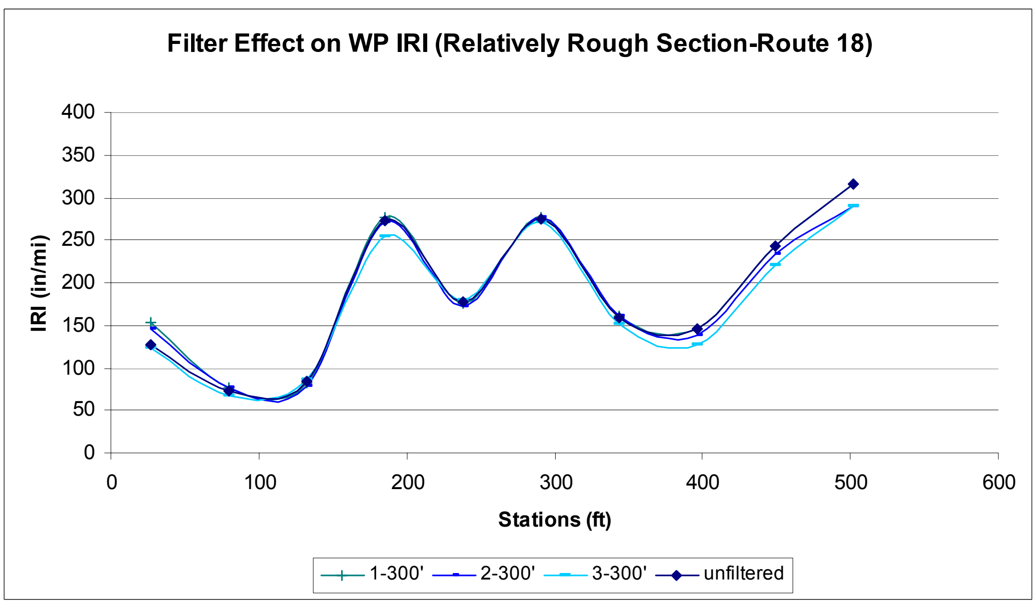


Figure 51c: Filter Effect on WP IRI (Relatively Rough Section - Route 18)

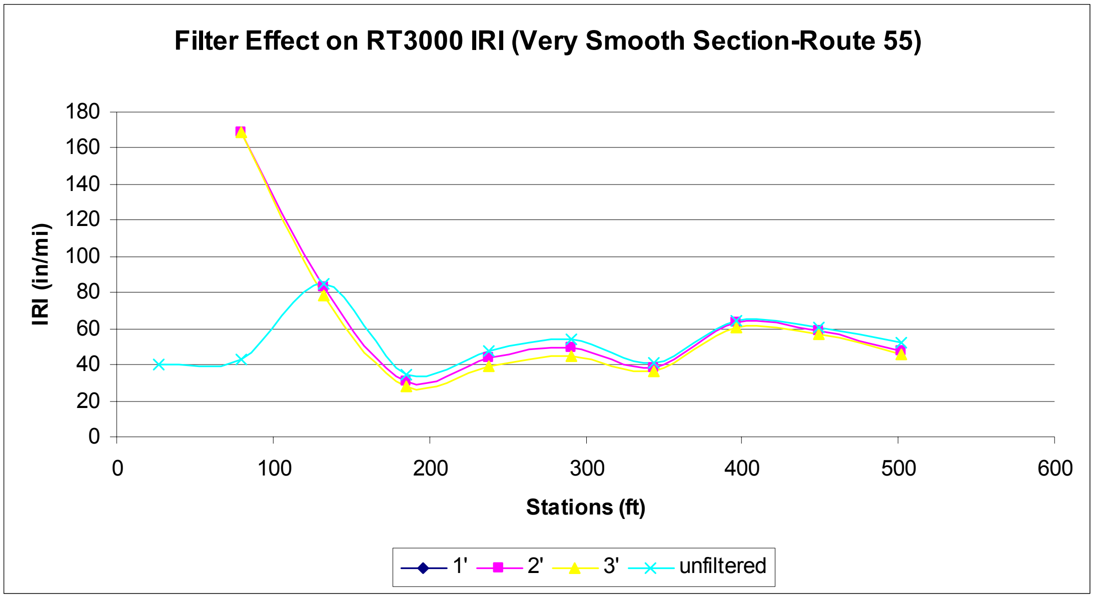


Figure 52a: Filter Effect on RT3000 IRI (Very Smooth Section - Route 55)

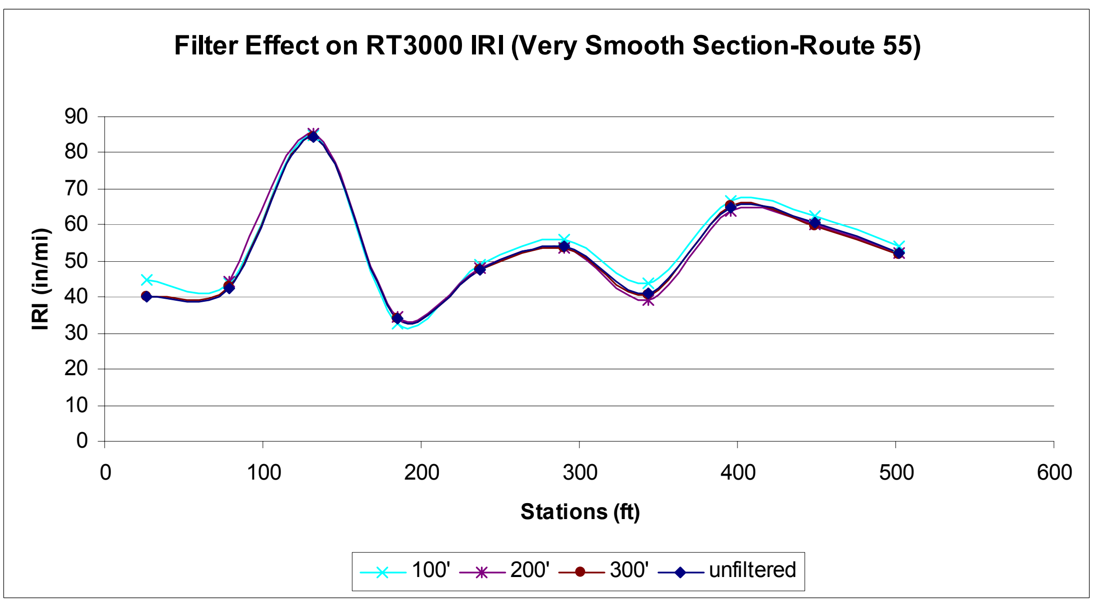


Figure 52b. Filter Effect on RT3000 IRI (Very Smooth Section - Route 55).

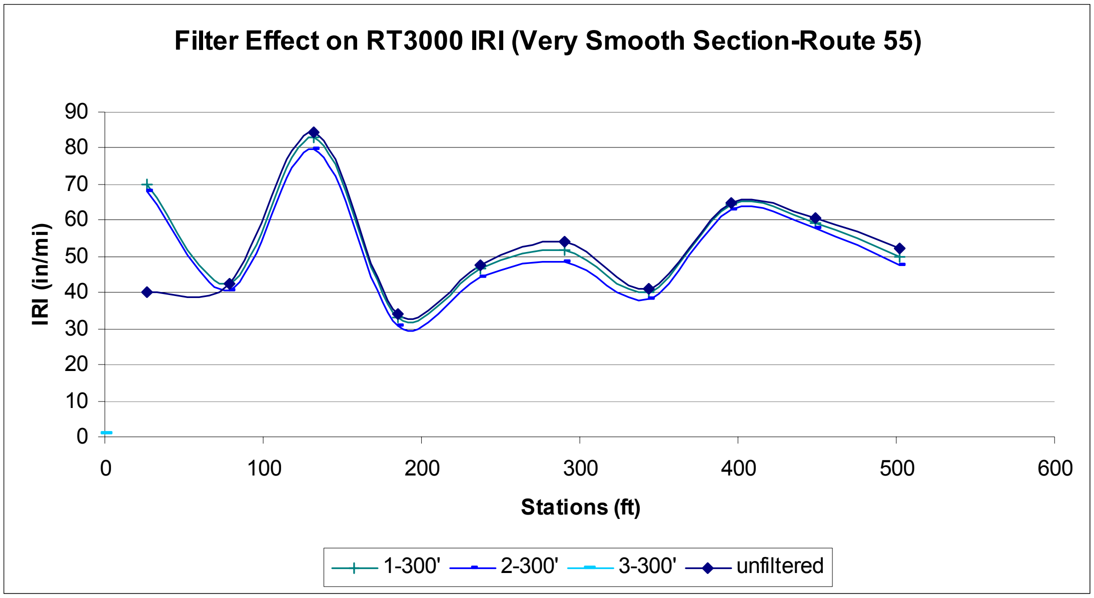


Figure 52c. Filter Effect on RT3000 IRI (Very Smooth Section - Route 55).

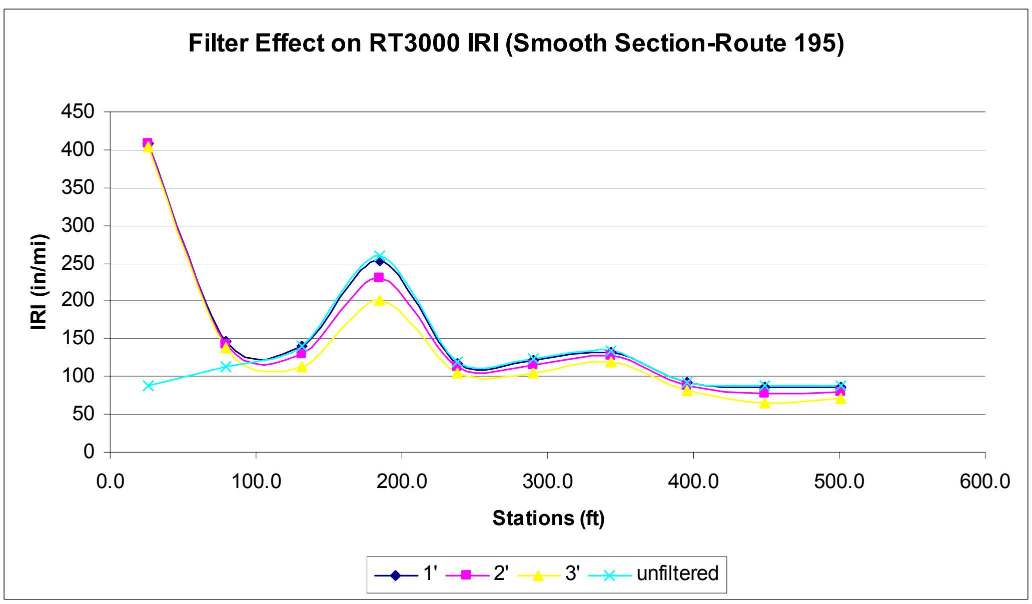


Figure 53a. Filter Effect on RT3000 IRI (Smooth Section - Route 195).

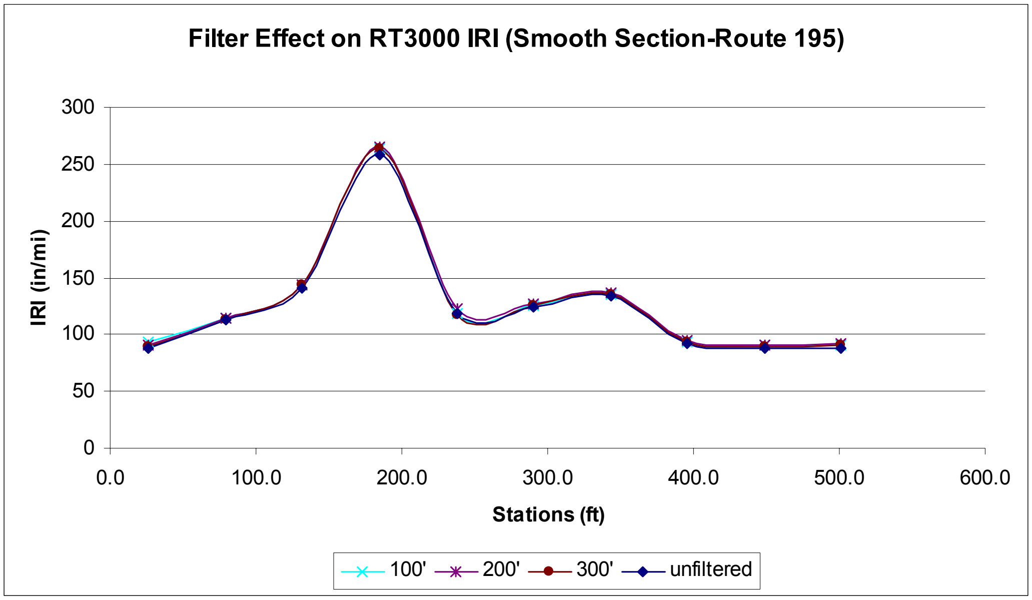


Figure 53b. Filter Effect on RT3000 IRI (Smooth Section - Route 195).

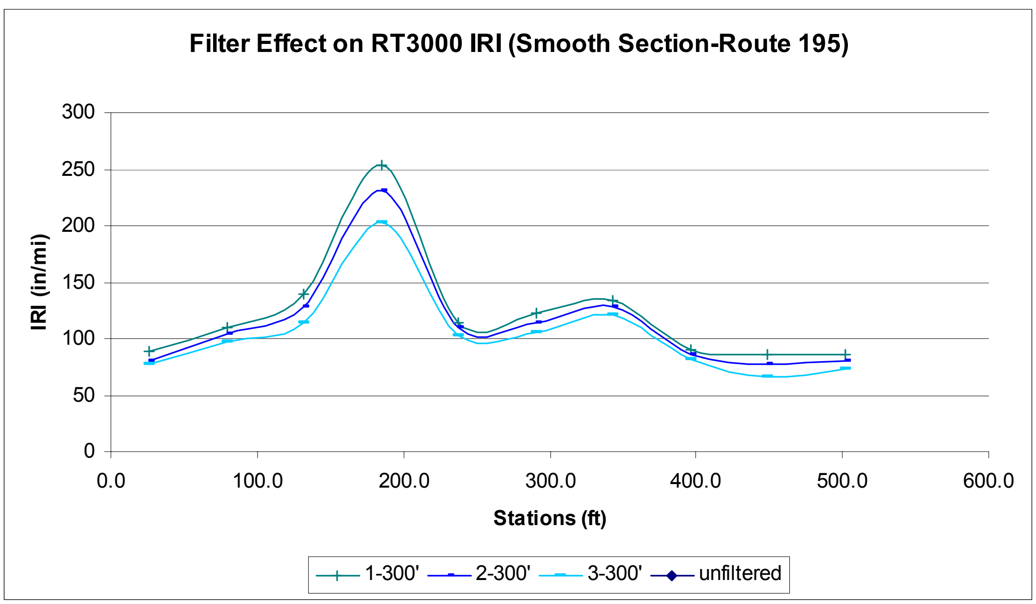


Figure 53c. Filter Effect on RT3000 IRI (Smooth Section - Route 195).

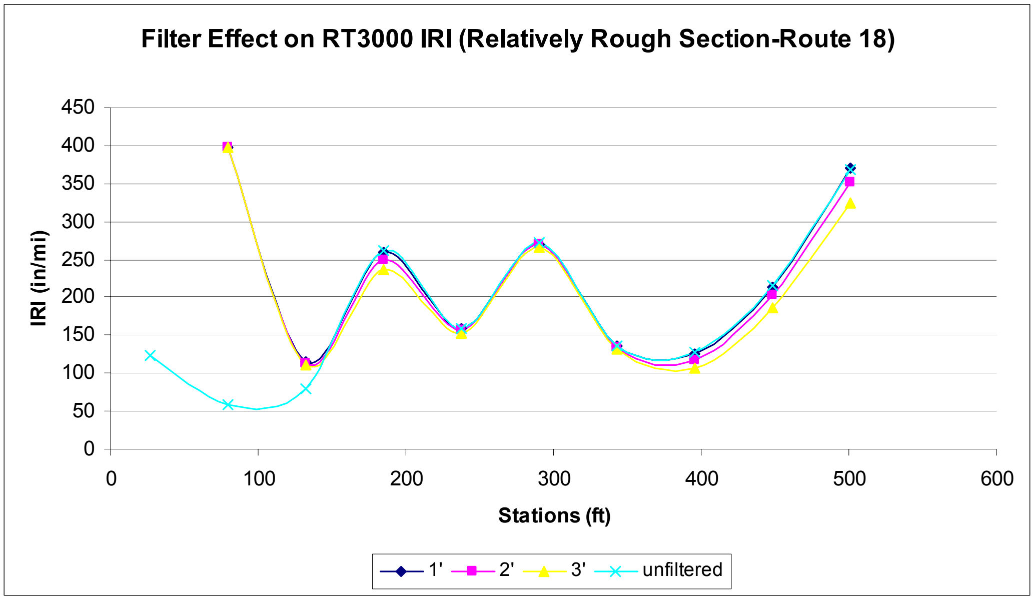


Figure 54a. Filter Effect on RT3000 IRI (Relatively Rough Section - Route 18).

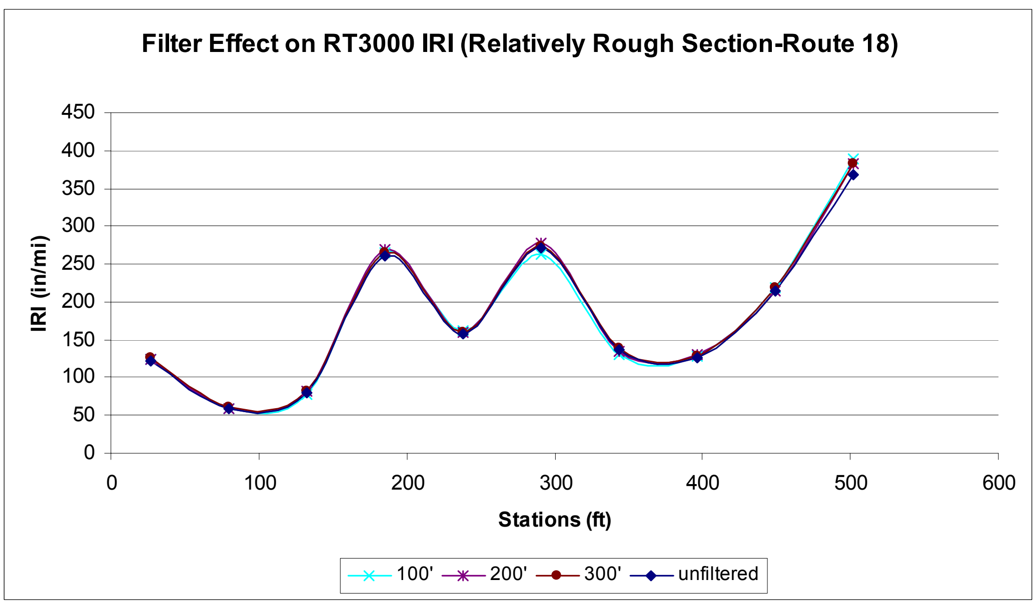


Figure 54b. Filter Effect on RT3000 IRI (Relatively Rough Section - Route 18).

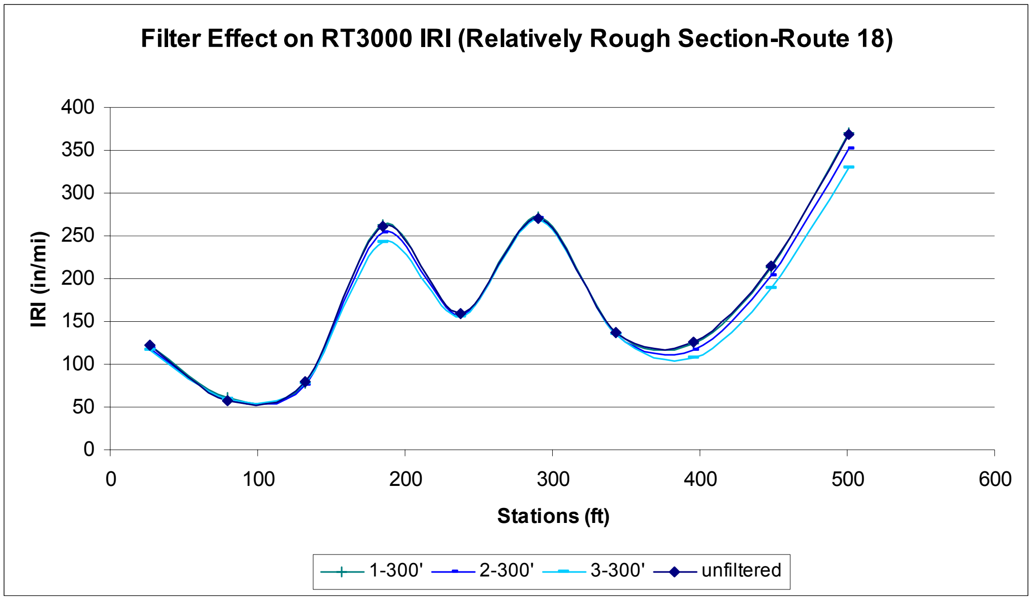


Figure 54c. Filter Effect on RT3000 IRI (Relatively Rough Section - Route 18).

Table 7. Difference in IRI [in/mi] between Unfiltered and Filtered Profiles for Entire 528-ft Sections.

	Low Pass Filters (ft)			High Pass Filter (ft)			Band Filters-Cutoff Length (ft)		
SECTION 1 - Smooth, IRI (in/mi)									
	1	**2**	**3**	**100**	**200**	**300**	**1-300**	**2-300**	**3-300**
R&L	0.52	7.61	18.22	1.29	0.89	0.13	0.61	7.66	19.21
WP	0	3.74	8.93	1.23	0.38	0.54	0.12	3.91	9.51
RT3000	33.77*	26.49*	16.16*	3.43	2.77	1.58	2.28	10.57	21.09
SECTION 11 - Very Smooth, IRI (in/mi)									
R&L	1.14	1.46	6.31	1.69	1.21	1.13	1.13	1.76	6.35
WP	0.6	0.36	3.89	0.83	0.45	0.45	0.96	0.33	4.88
RT3000	158.9*	151.2*	154.6*	1.21	1.92	2.42	2.42	0.28	2.65
SECTION 23 - Relatively Rough, IRI (in/mi)									
R&L	0.54	3.91	11.75	1.83	0.74	1.01	1.6	2.23	11.11
WP	0.14	7.14	11.25	1.46	0.79	1.1	3.88	3.39	10.18
RT3000	359*	354*	345*	0.19	1.48	1.51	1.49	7.41	13.92

*reported to ICC

Manufacturers, Proval and RoadRuf Computed IRI

Each equipment manufacturer provides an IRI routine as a part of the equipment software package. An investigation was made to quantify the differences between the IRI from the manufacture's software and that from post processed profile software, such as RoadRuf and Proval. In this investigation, RoadRuf was used to filter and calculate IRI from the profiles measured by the high-speed profilers. Since ARAN and Dynatest provide only filtered profiles, (300-ft high pass), a moving average 300-ft high-pass filter was applied on the RT3000 unfiltered profiles before computing the IRI.

The IRI computed from each manufacturer's software (RT3000, ARAN and Dynatest) was compared with those computed using RoadRuf and Proval, in order to investigate any differences in IRI routines. This exercise was done for only one 528-ft section in each roughness category.

Comparison for ARAN shows that differences between manufacturer, RoadRuf and Proval could be significant, figures 55 to 57. For the other high-speed profilers, (RT3000 and Dynatest), the agreement between all three IRI software routines is quite good for the each section investigated. Sample plots for RT3000 and Dynatest are shown in figures 58 to 63. All three high-speed profilers showed no consistent trend between IRI from manufacturer, RoadRuf and Proval.

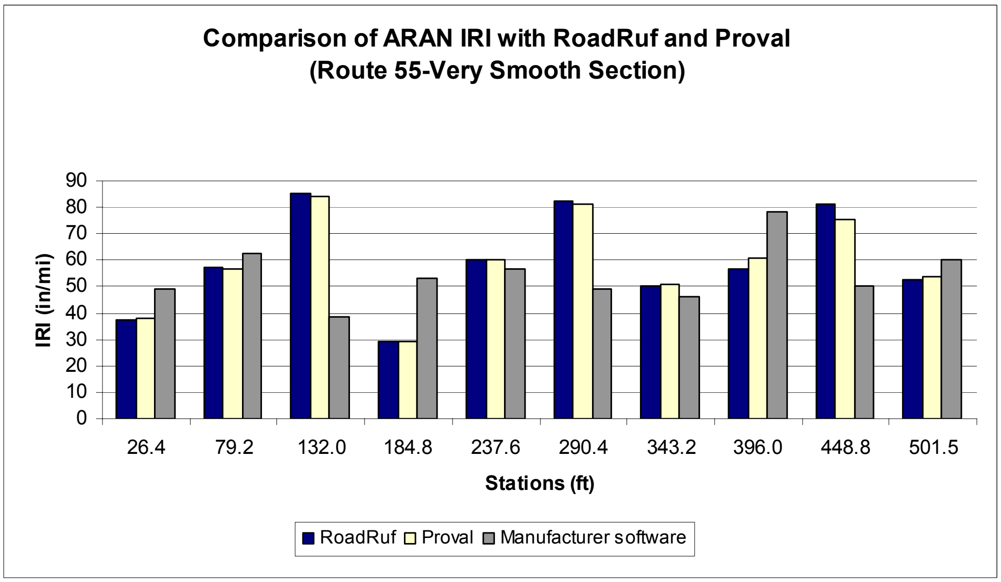


Figure 55. Comparison of ARAN IRI with RoadRuf and Proval (Route 55 - Very Smooth Section).

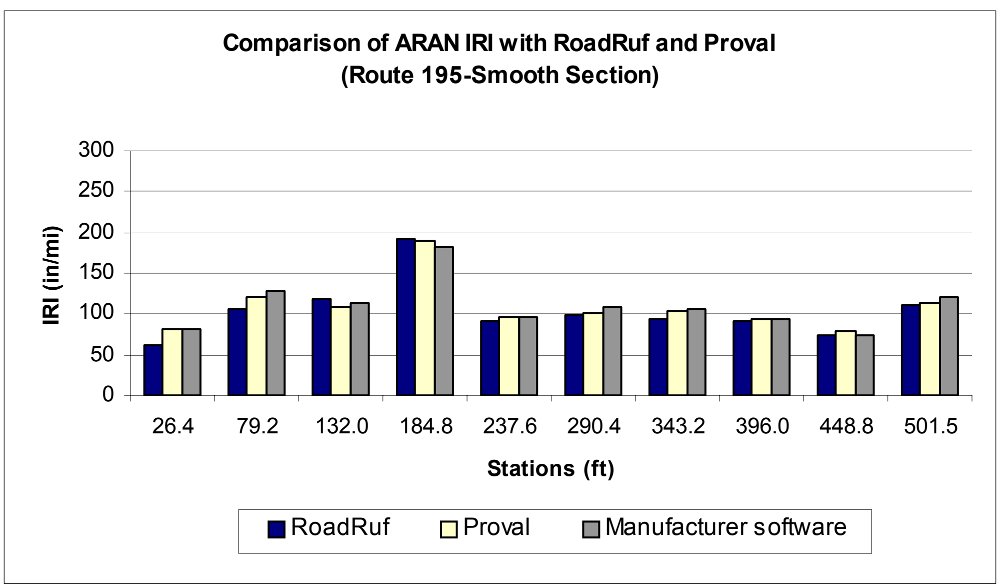


Figure 56. Comparison of ARAN IRI with RoadRuf and Proval (Route 195 - Smooth Section).

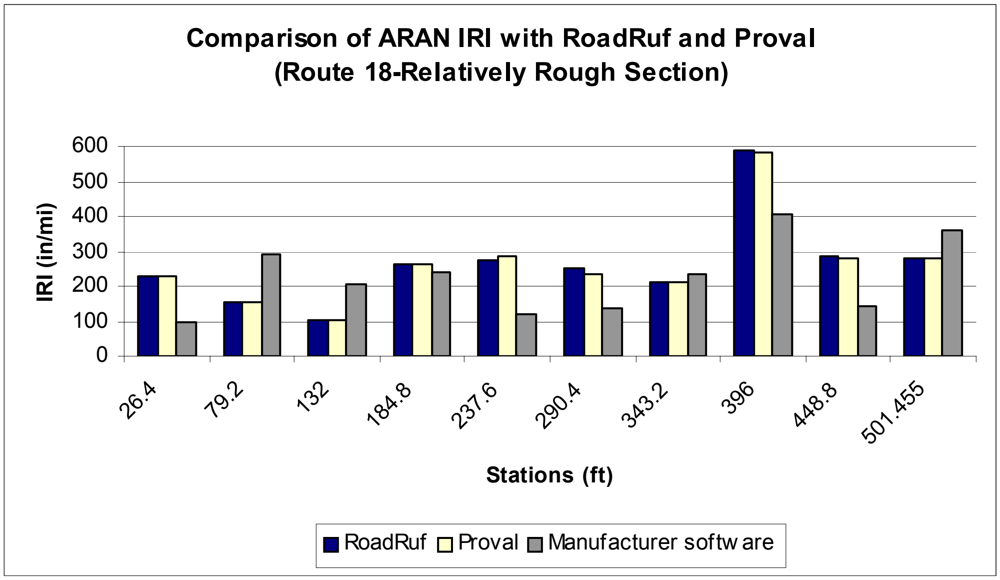


Figure 57. Comparison of ARAN IRI with RoadRuf and Proval (Route 18 - Relatively Rough Section).

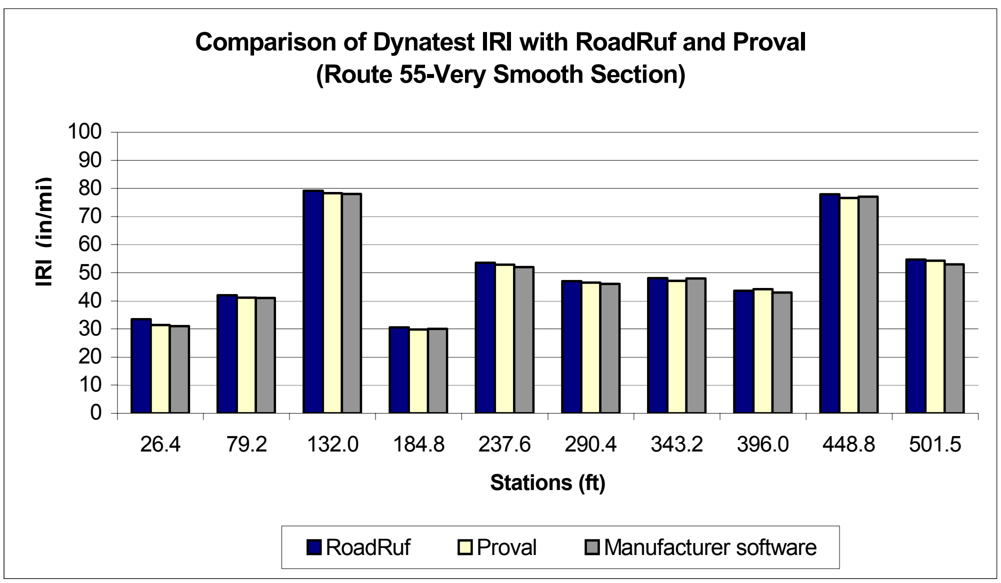


Figure 58. Comparison of Dynatest IRI with RoadRuf and Proval (Route 55 - Very Smooth Section).

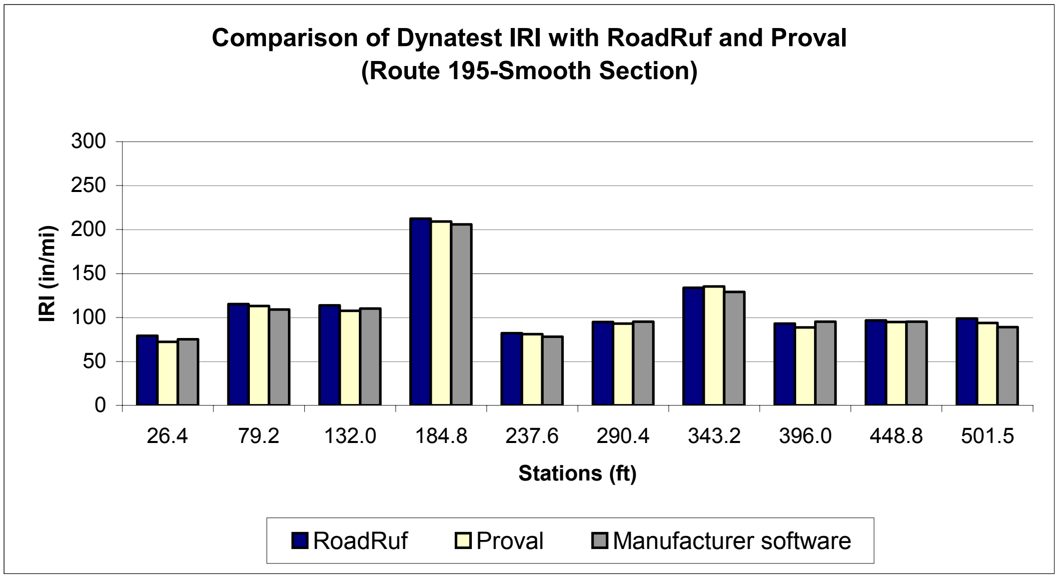


Figure 59. Comparison of Dynatest IRI with RoadRuf and Proval (Route 195 - Smooth Section).

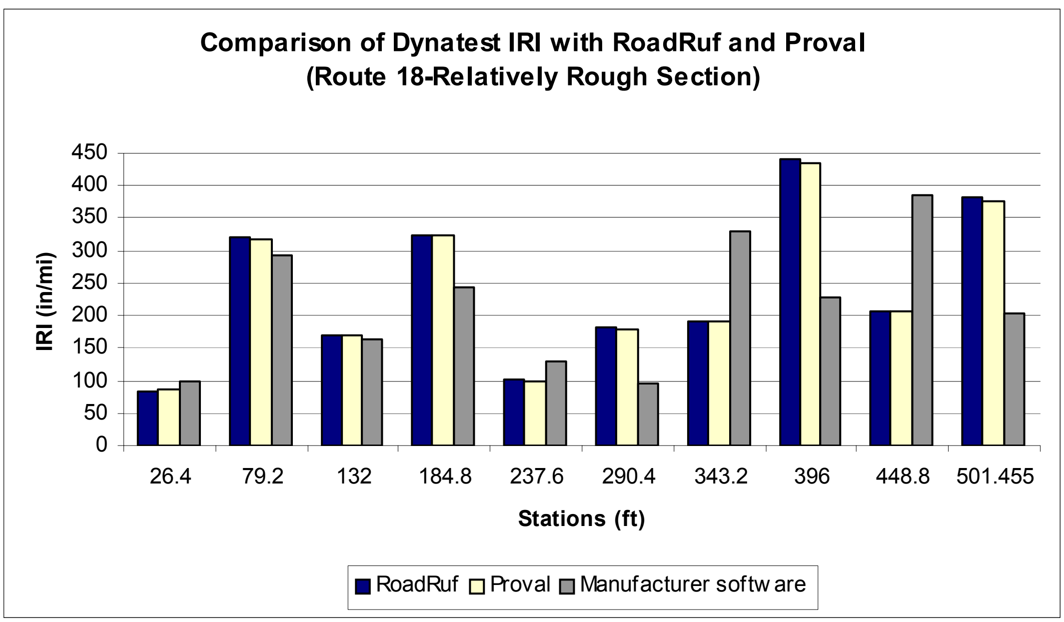


Figure 60. Comparison of Dynatest IRI with RoadRuf and Proval (Route 18 – Relatively Rough Section).

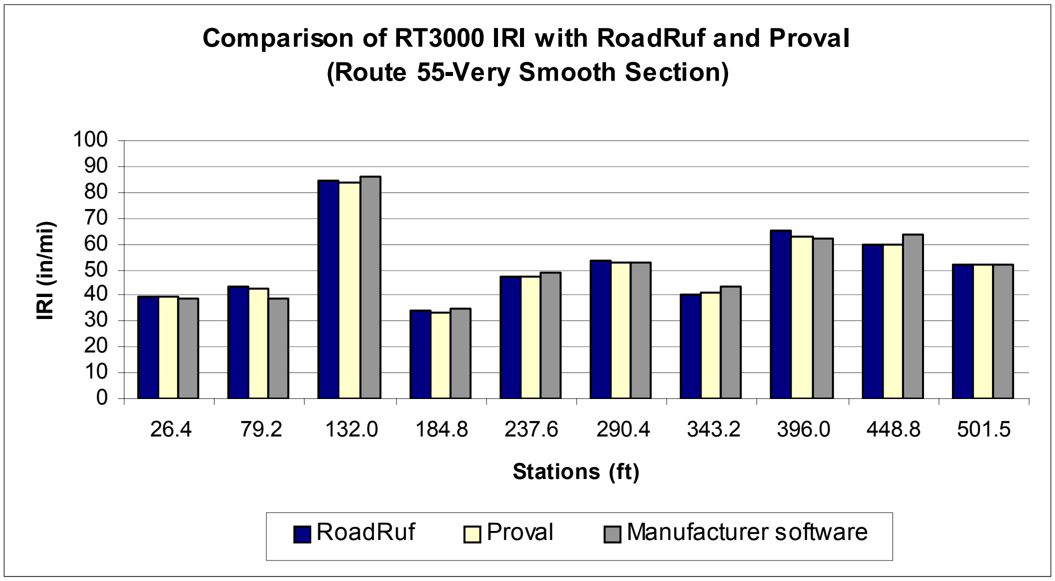


Figure 61. Comparison of RT3000 IRI with RoadRuf and Proval (Route 55 - Very Smooth Section).

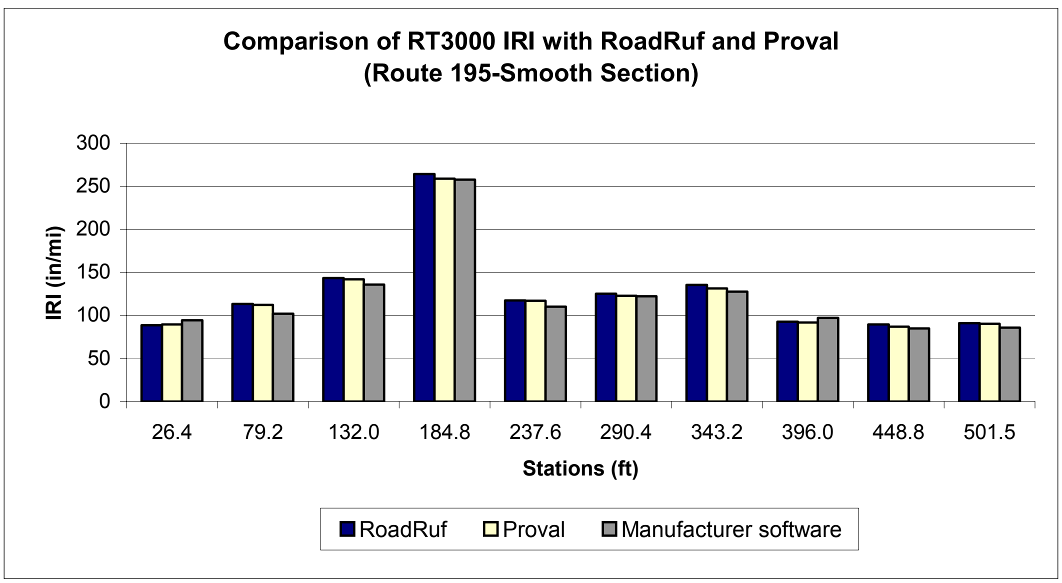


Figure 62. Comparison of RT3000 IRI with RoadRuf and Proval (Route 195 - Smooth Section).

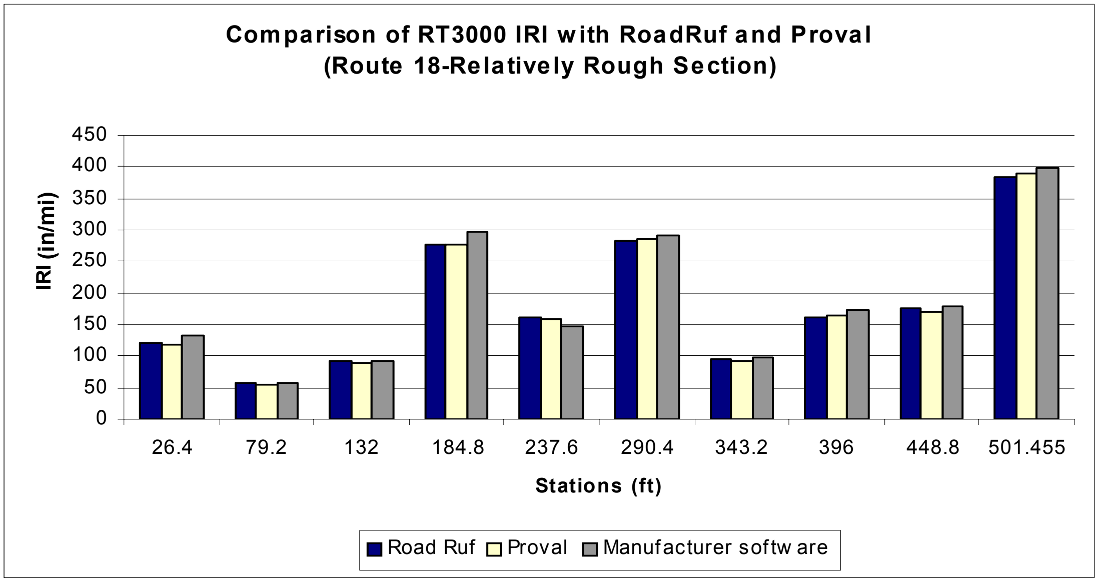


Figure 63. Comparison of RT3000 IRI with RoadRuf and Proval (Route 18 – Relatively Rough Section).

IRI Summary Interval Sensitivity Analysis

During the initial phase of the analysis, comparison of the overall computed IRI for each 528-ft section from the various equipment showed better agreement than the 52.8-ft subsections. This initiated an investigation of the sensitivity of IRI to the summary interval in order to determine the minimum interval at which the correlation among equipment is significantly improved.

The sensitivity of IRI to summary interval was investigated for each device by changing the IRI summary interval in RoadRuf. The intervals were selected to facilitate the breakdown of each 528-ft section into sub-sections greater than the IRI initialization length (36-ft) in RoadRuf.

The differences in IRI between individual equipment and WP are shown in table 8. Results are presented in terms of average and standard deviation for all runs within each test site. The standard deviation represents the variability of the differences between WP and the other equipments. The standard deviation decreases with increasing summary interval, that is, as IRI summary interval increases, the correlation with WP improves. Detailed IRI results for various intervals along the RWP of one section only within the smooth and very smooth roughness classes are shown in tables 9 and 10. Based on this investigation, 528-ft would be a suitable IRI summary interval for project level investigation.

Table 8. Differences between WP and Other Devices IRI for Various Intervals.

INTERVAL	52.8-ft		66-ft		88-ft		105-ft		132-ft		176-ft		268-ft		528-ft	
Route 55	**Avg**	**SD**	**Avg**	**SD**	**Av**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
R&L	13.95	11.17	14.08	9.98	13.79	9.31	13.75	8.88	14.07	8.27	13.74	6.41	13.84	6.01	14	5.97
ARAN	7.12	8.73	6.72	5.30	6.00	4.47	4.60	4.87	4.83	5.02	2.80	2.49	3.29	2.21	2.95	0.54
Dynatest	5.77	4.48	5.72	3.79	5.05	3.06	3.84	2.62	4.01	2.92	3.60	2.31	3.38	2.56	3.37	1.99
RT3000	9.40	6.09	8.68	5.44	6.28	4.06	5.11	3.93	5.48	4.56	3.11	2.07	3.28	2.45	1.79	1.62

INTERVAL	52.8-ft		66-ft		88-ft		105-ft		132-ft		176-ft		268-ft		528-ft	
Route 195	**Avg**	**SD**	**Avg**	**SD**	**Av**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**	**Avg**	**SD**
Dynatest	16.58	14.72	15.00	12.80	14.30	11.10	13.70	12.00	12.10	12.23	11.67	10.23	10.24	9.48	10.22	3.40
R&L	47.25	24.14	41.22	19.81	40.73	15.91	41.31	15.49	41.36	14.02	40.60	10.25	41.06	6.42	41.08	1.69
ARAN	16.60	15.22	16.07	14.08	21.76	19.13	19.77	12.03	17.06	11.14	21.03	17.86	14.53	11.10	14.61	4.38
RT3000	21.67	14.54	16.76	13.02	19.43	19.31	16.66	12.48	15.11	11.22	18.81	15.12	14.51	10.22	14.14	7.78

Table 9. Interval Sensitivity per Equipment for Route 55 (Very Smooth Section).

	52.8'					66'					88'					105'					132'					176'					268'					528'				
Sub-section	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL
1	40	38	33	37	59	43	41	35	45	57	43	48	39	47	60	41	47	36	46	58	56	53	42	55	61	53	57	49	57	67	49	53	46	54	66	51	59	50	56	67
2	43	57	42	55	59	68	65	50	65	65	63	65	59	67	73	59	57	54	59	67	43	54	51	54	73	46	60	46	49	67	54	65	54	59	67					
3	84	85	79	88	87	39	53	54	50	70	42	47	42	48	66	50	71	50	54	74	46	64	46	48	61	56	60	55	63	65										
4	34	29	31	30	47	47	55	49	57	76	49	72	50	49	69	53	53	45	52	58	61	65	62	69	72															
5	47	60	54	62	84	54	74	47	48	65	57	62	52	56	62	55	67	65	72	76																				
6	54	82	47	46	66	38	54	44	48	58	54	58	58	69	69																									
7	41	50	48	48	63	71	80	71	74	83																														
8	65	57	44	57	53	51	50	52	64	61																														
9	60	81	78	76	87																																			
10	52	53	55	67	64																																			

Table 10. Interval Sensitivity per Equipment for Route 195 (Smooth Section).

	52.8'					66'					88'					105'					132'					176'					268'					528'				
Sub-section	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL	RT3000	ARAN	Dynatest	WP	RL
1	89	62	79	56	102	82	95	77	56	94	88	97	83	65	106	101	101	93	81	121	112	102	103	87	128	143	128	100	94	122	144	118	117	105	139	125	109	109	100	139
2	113	105	115	104	139	142	111	128	117	161	198	159	117	123	138	200	149	158	142	159	176	136	130	124	149	137	103	133	126	171	104	98	100	94	140					
3	144	117	114	93	115	225	181	169	164	167	146	103	149	133	171	120	98	87	89	141	126	104	110	112	165	92	94	93	81	125										
4	264	191	212	190	202	126	90	91	84	130	130	104	117	117	170	112	99	112	112	166	83	91	91	74	116															
5	117	90	82	83	136	129	103	114	116	182	101	97	88	83	143	88	95	94	74	111																				
6	125	98	95	94	145	123	105	107	109	146	83	92	98	79	107																									
7	136	94	134	139	178	88	89	88	72	140																														
8	93	90	93	85	154	79	94	95	76	92																														
9	90	74	97	75	142																																			
10	91	110	99	74	78																																			

IRI Limits for Different Roughness Categories

Table 11 and figure 64 show the IRI values for all the 528-ft sections/devices considered in this study. As can be seen from this figure, there are distinct differences in the IRI values of the three roughness classes. The IRI values for the very smooth category is in the range of 50's in/mile. The corresponding ranges for the smooth and relatively rough categories are 110's and greater than 180 in/mile, respectively. This suggests that IRI limits can be established to classify pavement sections in the three roughness classes with no overlaps, as can be seen from figure 64.

Table 11. Comparison of IRI of Different Sections/Equipment

	R&L	WP	ARAN-40	Dynatest-40	RT3000-40
Route 55 (very smooth)					
S11	66.785	56.457	59.329	51.017	51.951
S12	64.141	55.224	51.890	54.736	53.460
S13	58.910	51.186	50.073	46.750	45.744
Route 195 (smooth)					
S1	139.130	99.297	103.280	111.970	126.220
S3	124.790	106.600	113.040	112.790	103.704
S4	115.650	105.100	113.510	111.060	107.270
Route 18 (relatively rough)					
S23	187.841	188.107	359.091	233.883	183.385
S24	336.684	336.579	415.742	328.957	183.385
S25	335.167	262.336	198.165	302.349	331.443

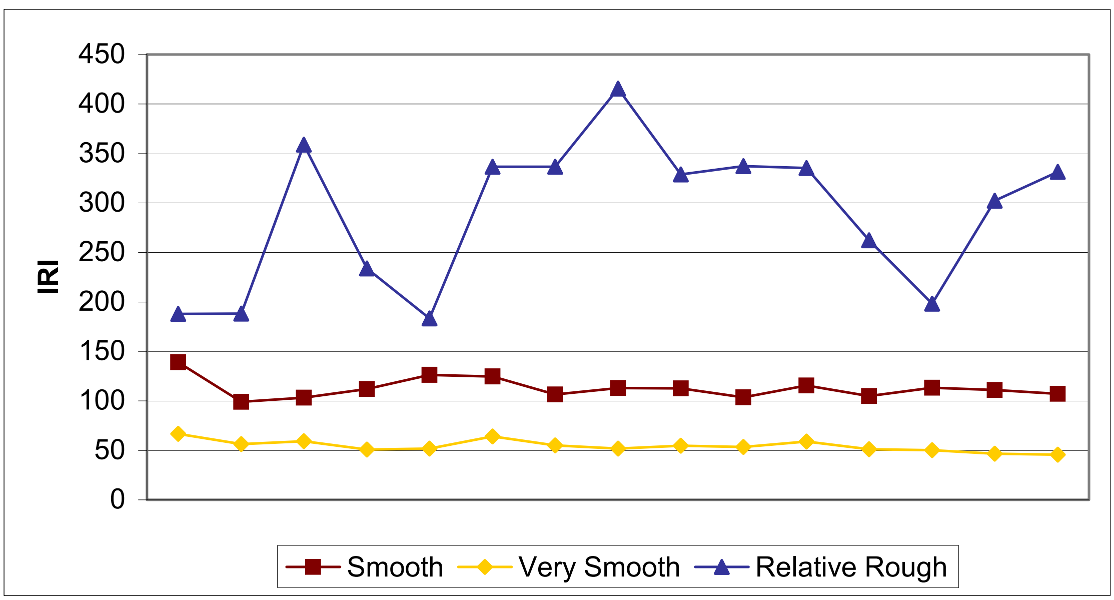


Figure 64. Comparison of IRI of Different Sections/Equipment

SELECTION OF NJDOT SPP AND EQUIPMENT CORRELATIONS

Selection of NJDOT SPP

Although R&L survey provides the highest accuracy of all devices, some major constraints of this survey exist. These constraints include the time and effort required to complete the survey, which is very significant. On the other hand, WP is a precision instrument designed to facilitate the efficient collection and presentation of continuous paved surface information such as profile and IRI. Recall figures 8 to 10 and those presented in Appendix B, the profiles measured with WP matches very well those measured with R&L. Therefore, the WP was selected as the NJDOT SPP device that will be used to calibrate high-speed profilers. Correlation models were developed between the measurements of WP and high-profilers and presented later in this section. Also, a calibration/correlation procedure that can be used to calibrate/correlate high-speed profilers with respect to WP is presented in this section. In addition, since there are observed differences between the IRI values calculated using public-domain software packages, such as RoadRuf, and those reported by the devices, as presented earlier in this report, RoadRuf is selected to be the official ride statistic analysis package for NJDOT SPP device.

Filter Recommendations

Based on the analysis performed on the profilers collected using R&L, WP and RT3000, to investigate the impact of filter characteristics on the reported roughness index, IRI and Ride Number (RN), the following is the recommended filter parameters for NJDOT. It should be noted that since RoadRuf is the selected software for NJDOT profile analysis, the selected filter parameters are available in RoadRuf. However, the filter analysis should be performed on unfiltered profilers, and not a “pre-filtered” profile.

Filter Type: Moving average

High Pass: 300 ft

Low Pass: 0

Software: RoadRuf

Development of Correlation Models with NJDOT SPP

Correlation analysis was performed to develop correlation models that will be used to correlate the measurements of the high-speed profilers to those of WP. The correlation analysis was performed on the average of the three runs for both RWP and LWP at an IRI interval of 52.8ft using a high pass filter of 300ft. Separate analysis was performed for each speed. The maximum and minimum R^2 values are 0.9363 and 0.7242, respectively. It should be noted that results from Route 18 were not included in the correlation analysis. Figure 65 shows a summary the R^2 of the correlation models developed between WP and the high-speed profilers for different testing speeds. Table 12 shows the developed correlation models, while figures 66 to 68 show graphical presentations of these models.

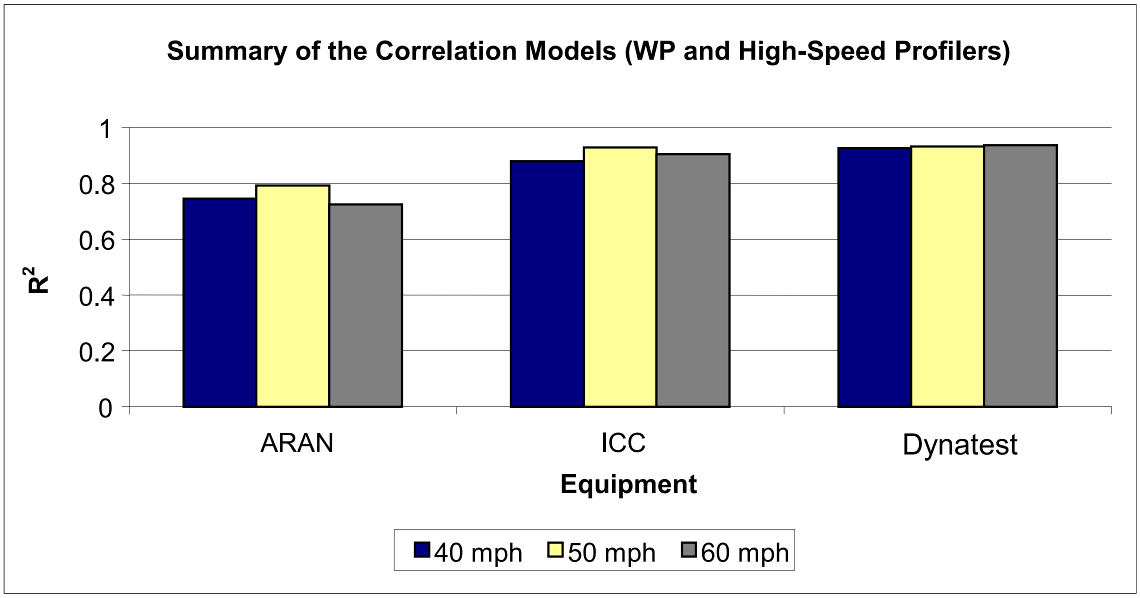


Figure 65. Summary of the Correlation Models (WP and High-Speed Profilers).

Table 12. WP Correlation Models.

Profiling Device	Equation: $IRI_{spp} = a_v + b_v{*}\ IRI_v + c_v{*}\ (IRI_v)^2$	R^2
ICC 40	Y=0.9292x+3.815	0.879
ICC 50	Y=0.9491x+3.5916	0.9279
ICC 60	Y=0.9109x+5.4712	0.9042
ARAN 40	Y=0.8327x+9.0275	0.7452
ARAN 50	Y=0.8157x+9.4143	0.7915
ARAN 60	Y=0.8249x+7.4742	0.7242
Dynatest 40	Y=0.8893x+6.983	0.9262
Dynatest 50	Y=0.8979x+6.7656	0.9329
Dynatest 60	Y=0.9071x+4.6573	0.9363

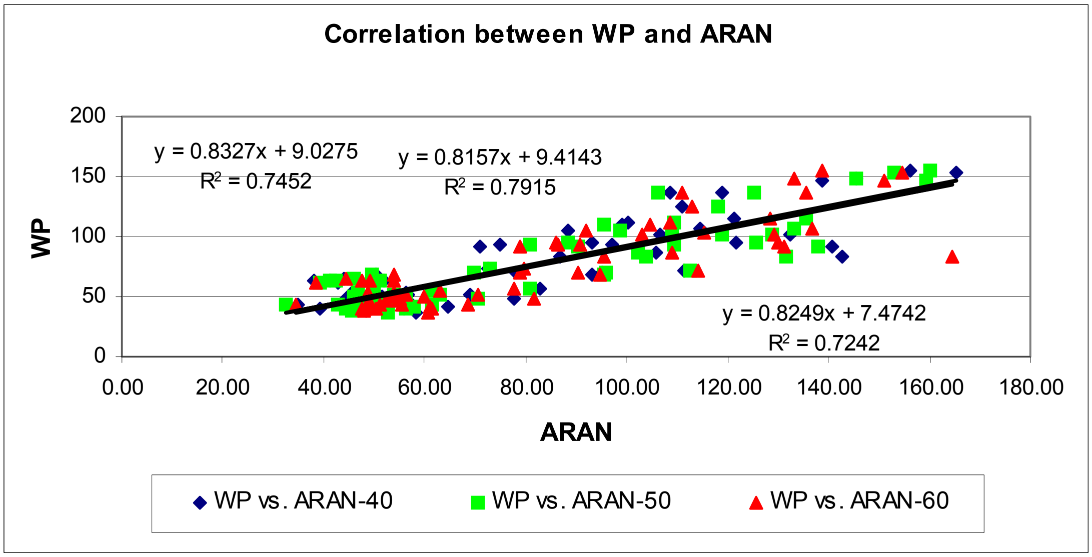


Figure 66. Correlation between WP and ARAN.

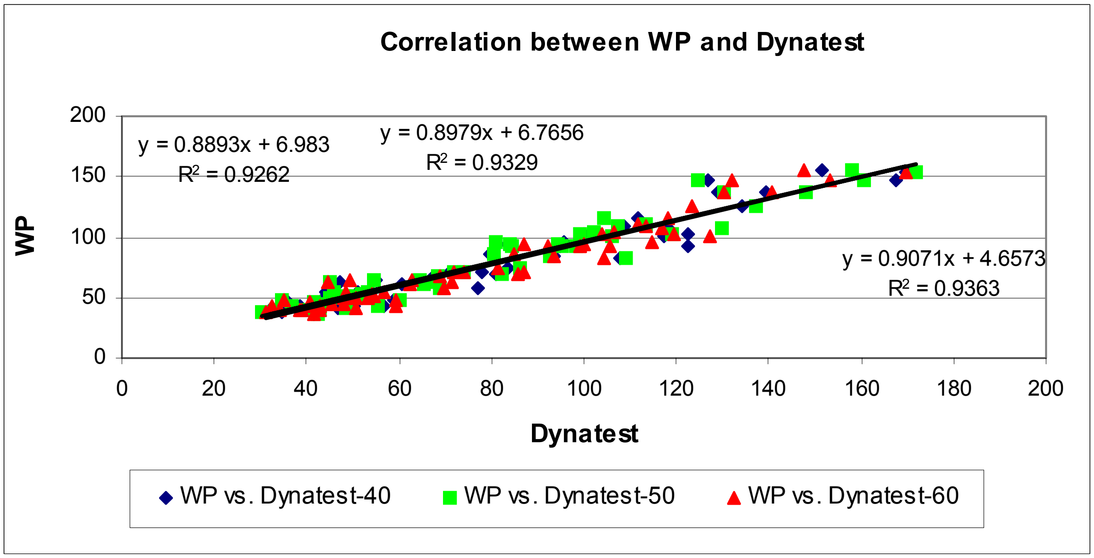


Figure 67. Correlation between WP and Dynatest.

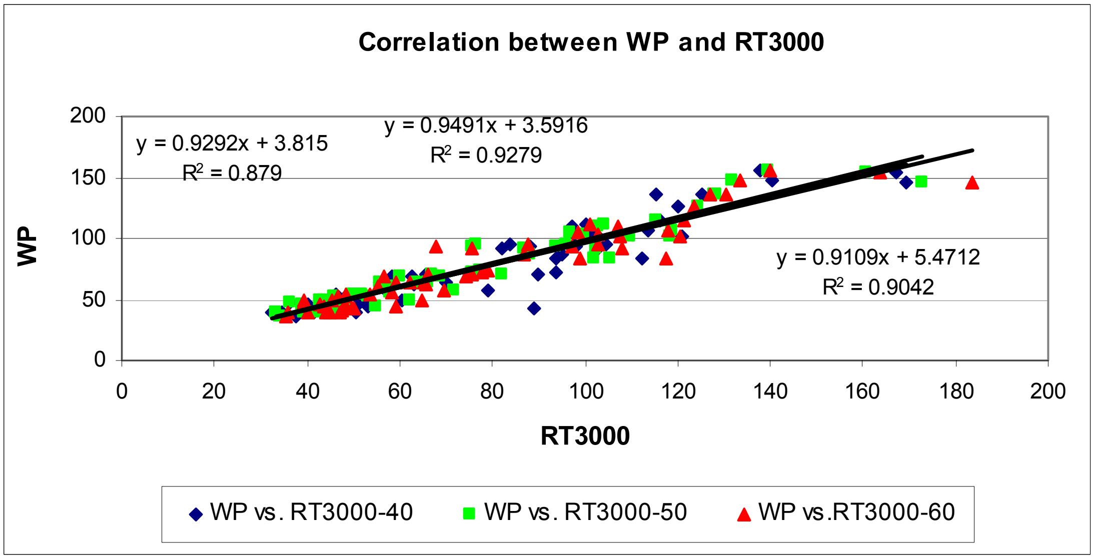


Figure 68. Correlation between WP and RT3000.

Calibration/Correlation Procedure for Other Profilers

The SPP is used to calibrate/correlate other profilers with WP. All profiling devices that will be used in the NJDOT pavement smoothness quality control/acceptance program must be calibrated/correlated with NJDOT SPP. This will ensure the compatibility of the measurements reported by different devices.

Before calibration/correlation with the SPP, the profiling device must be calibrated as per the manufacturer's recommendation. Such calibrations shall include:

Calibration of Height Sensors

Calibration of Accelerometers

Calibration of Distance Measuring System

<u>Calibration Sections</u>

The NJDOT will establish three asphalt surfaced calibration sections. One of these sections will have IRI ≤ 70 in/mi, one will have 90≤IRI≤120 in/mi and the third an IRI > 120 in/mi. These limits are based on the expected range of IRI for a new or rehabilitated pavements. The desired total length of each section is 0.5 mile to allow adequate running/stopping distances for high-speed profilers. The actual testing length that will be used in the calibration/correlation will be only the middle 0.3 mile (1,584-ft) portion of the 0.5-mile section. The beginning and ending points of each section will be identified with reflective tape that is used to trigger the auto-start of high-speed profilers. The left and right wheel paths will be marked in accordance to AASHTO PP 31-96 (2000) to help reduce the lateral wandering for repeated runs and to select these sections from low traffic highway segments.

NJDOT will perform three runs with NJDOT SPP on each wheel path of these sections. The right and left wheel path IRI values will be calculated separately for each run. These IRI values will be calculated for 0.01-mile (52.8-ft) intervals, using RoadRuf. The average of the 3 runs will then be determined for the right and left wheel paths. It is desired that NJDOT repeats the testing every 6 months and update the average IRI values, then averaged to obtain a representative IRI for the section. However, the IRI values should not be older than one year.

Profile Data Collection and Analysis

The profiler to be calibrated/correlated to NJDOT SPP is required to obtain five repeat runs at each speed along both wheel paths. In the case of high-speed profilers, testing shall be conducted at 3 speeds, 40, 50 and 60 mph. Inertial profilers shall be operated and profiles collected according to AASHTO PP 50-03 “Standard Practice for Operating Profilers and Evaluating Pavement Profiles” and ASTM E 950, “Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces with an Accelerometer Established Inertial”, respectively. The profiler shall meet the minimum requirements and specifications stated in AASHTO M 11, “Standard Equipment Specification for Inertial Profiler” and ASTM E 950.

The precision shall be based on IRI and shall meet the following requirements:

The standard deviation for IRI of the five runs at each speed shall not exceed ± 5 percent of the mean IRI. Each wheel path shall be analyzed separately. If this condition is met for each run, the mean IRI for all five runs shall be reported as the IRI of the test section. Runs that do not meet this condition will be excluded from the analysis.

The minimum number of runs that should pass this condition is three runs. Another 5 runs will be performed if only one or two runs meet this condition.

The average of the repeated runs of the profiler that meets the above condition, (at least 3 runs), will be correlated with the average of the 3 runs of NJDOT SPP. This correlation will be performed for each speed separately. Regression analysis shall be performed on the profiler and SPP data to develop a correlation model, determine the regression coefficients (a, b and c). It is recommended that the regression be limited to straight line correlation, i.e. c = 0 in the formula shown below.

$$IRI_{spp} = a_v + b_v{*}\ IRI_v + c_v{*}\ (IRI_v)^2$$

Where:

IRI_{SPP} = average 0.01 IRI values measured using NJDOT SPP profiler
IRI_v = 0.01 IRI values measured using the calibrated profiler at speed “V”
a_v, b_v, c_v = regression coefficients for speed “V”.

The correlation models are then used to correlate the IRI measurements of the profiler to those of NJDOT SPP. It should be noted that the developed correlation models are valid only for the IRI values calculated from the profiles using RoadRuf. Also, these steps should be repeated at least once a year or every time NJDOT update the SPP calibration data set.

TRADITIONAL RIDE STATISTICS

The IRI is the most commonly used ride statistic in North America. The FHWA uses IRI to monitor the condition of the National Highway System (NHS). Each state is mandated to report the IRI values of the NHS sections within the state jurisdiction to FHWA on yearly basis, with some exceptions. FHWA uses two IRI values of 90 and 170 in/mi to define good and triggered sections, respectively.

Although the purpose for which FHWA is using IRI, network-level management application, is significantly different from the scope of this project, detailed project-level investigation, IRI was used in the analysis presented earlier to investigate the impact of testing parameters on the reported results. The reason for that is the wide spread of using IRI, nation and world wide, and the familiarity with the IRI scale. Although it is true that each organization is more familiar with the organization specific indices, such as the RQI and %DL for NJDOT, however this experience is a sort of local experience. Therefore, it was felt that using IRI to illustrate the impact of testing parameters, such as speed, equipment,….etc., will facilitate transferring this effort and knowledge to other states.

In this section, some background information is provided about the traditional ride statistics that have been (or can be) used for smoothness acceptance. In the following section of this report, the new ride statistics developed as a part of this project to overcome some of the limitations of the traditional ride statistics are presented. Also, advanced profile analysis techniques are presented. These techniques can be used as a diagnoses tool.

The following sub-sections provide some background information about some of the traditional ride statistics, which are listed below. Following this background information is the results of using these ride statistics, other than IRI, for some of the test sections considered in this project.

- IRI
- RN
- Profile Index (PI) determined from Profilograph inspections, such as California Profilograph
- %DL determined from RSE inspections, which is the current smoothness acceptance specifications for NJDOT

It should be noted that PI and %DL are calculated through computer simulation and not field measured.

Background

<u>IRI Background</u>

In 1982, the World Bank developed an international index for classifying the road longitudinal roughness. This index is called the IRI. IRI-value is determined from the longitudinal profile of the road. The method of measuring the profile can vary; however, there is a minimum accuracy level that should be achieved. The IRI value of the measured profile is determined using the Reference Quarter-Car Simulation model. The Quarter-Car model, shown in figure 69, has standard tire, suspension and damper properties. This model moves at a constant speed along the determined profile and vertical movement of the sprung and unsprung mass is calculated from the movements of the axle and the body as the sum of the vertical movement (m/km or mm/m). One advantage of this model is that whether the roughness is viewed as deviations in elevation (displacement inputs), slope (velocity inputs), or change of slope (acceleration inputs) the quarter car model responds in a defined manner. The quarter care simulation is created to theoretically simulate a response type system assuming the properties of the "Golden Car" [(5)].

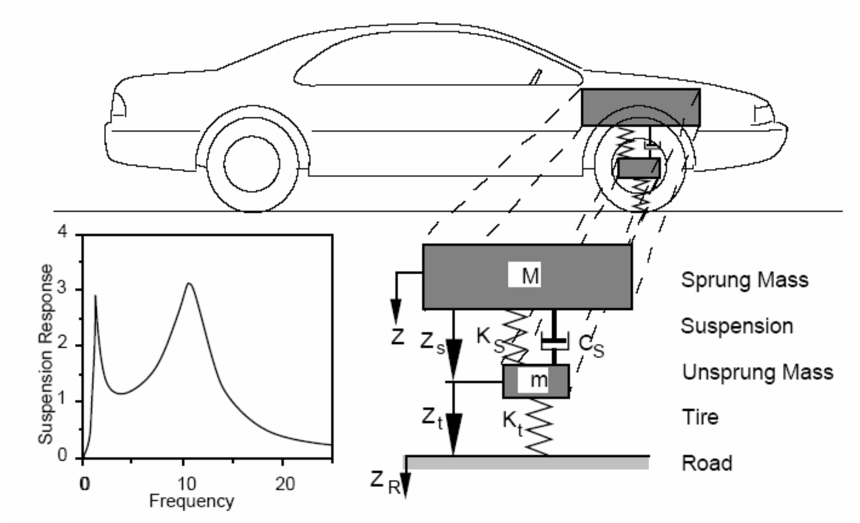


Figure 69. IRI – Quarter Car Model[(5)].

Several studies were performed on IRI and the quarter car model. Some of these studies were concerned with the relationship between the model input, longitudinal roughness, and the model output, IRI. This relationship can be best described with the gain factor, which is the ratio between the amplitude of the input and output waves. Figure 70 shows the gain factor as a function of wave length. As can be seen, the frequency response of the quarter car extends from approximately 0.5 to 20 Hz. with some emphasis on roughness at the body bounce frequency and the axle resonance frequency. At very low frequencies (corresponding to long wavelengths in the road) the suspension response is zero because the wheel and the vehicle body move up and down together. Road inputs at frequencies near one Hertz cause the sprung mass to resonate on the suspension, producing stroke that is slightly greater than the road input. The response is maintained up through frequencies near 10 Hertz where axle resonance occurs. Above the axle resonant frequency the response again drops to zero as the road bumps simply deflect the tire without producing significant suspension stroke.

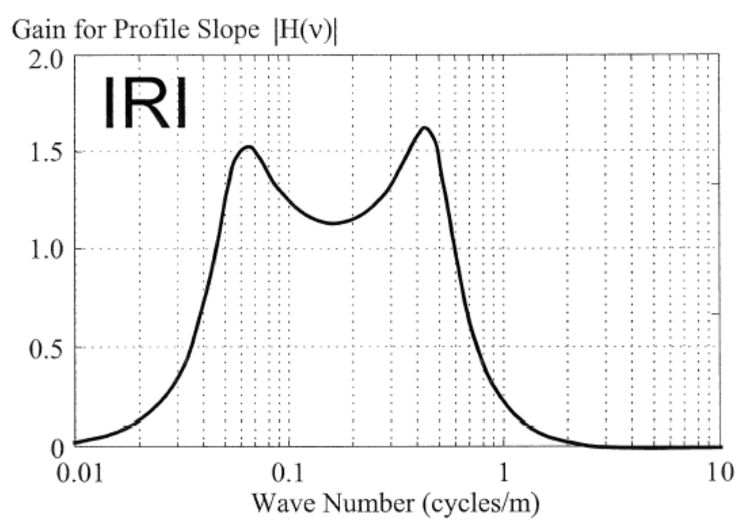


Figure 70. Quarter Car Model Gain Factors[(5)].

The Gain-Wave Number relationship highly dependent on the levels of the quarter car model input parameters, which represent the vehicle and the travel speed. The relationship presented in figure 70 is for the Standard IRI input parameters, Golden Car parameters. Several sensitivity analyses were performed to show the impact of the quarter car model input parameters on the model output, and hence the Gain-Wave Number relationship. Figure 71 shows an example of the impact of the quarter car model input parameters on the model output.

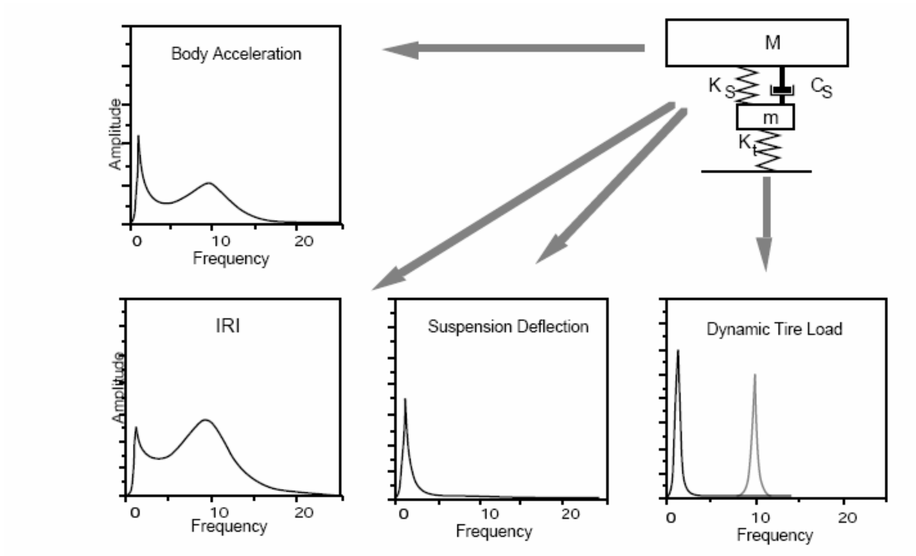


Figure 71. Quarter Car Sensitivity[6].

RN Background

Although IRI is the most commonly used ride statistic to monitor road longitudinal roughness, it is often criticized because it is not the “best” index for quantifying specific road roughness qualities or does not conform to local preferences for a roughness index[6].

The National Cooperative Highway Research Program (NCHRP) sponsored two research projects in the 1980’s to investigate the effect of longitudinal roughness on ride comfort. The objective of these studies is to determine how the road profile characteristics are linked to the public subjective opinion about the road. In these two studies, the Mean Panel Ratings (MPR) were determined experimentally on a 0-to-5 scale for test sites in several States. Longitudinal profiles were obtained for the left- and right-hand wheel tracks of the lanes that were rated.

The researchers of these studies investigated a quarter-car analysis nearly identical to IRI, and found significantly less correlation between the quarter-car index and panel rating than between a profile index based on short wavelengths. Profile-based analyses were developed to predict MPR. A method was developed in which Power Spectral Density (PSD) functions were calculated for two longitudinal profiles and reduced to provide a summary statistic called PI (profile index). The PI values for the two profiles were then combined in a nonlinear transform to obtain an estimate of MPR[6].

In 1995, some of the data from the two NCHRP projects and a panel study conducted in Minnesota were analyzed again in a polled-fund study initiated by FHWA. The objective was to develop and test a practical mathematical process for obtaining RN. The method was to be provided as portable software similar to that available for the IRI, but for predicting MPR rather than IRI. The profile data in the original research were obtained from several instruments. Most were measured with a K.J. Law Profilometer owned by the Ohio Department of Transportation, and are thought to be accurate. A few other test sites were profiled with instruments whose validity has been questioned. The new analyses were limited to 140 test sites that had been profiled with the Ohio system.

A new profile analysis method was developed that is portable. The software was tested on profiles obtained from different systems on the same sites, and similar values of RN were obtained. It predicts MPR slightly better than previously published algorithms.

Figure 72 shows the sensitivity of RN. As discussed earlier, this shows the response of the profile index for a slope sinusoid. If given a sinusoid as input, the RN filter produces a sinusoid as output. The amplitude of the output sinusoid is the amplitude of the input, multiplied by the gain shown. The maximum sensitivity is for a wave number of 0.164 cycle/m (0.05 cycles/ft), which is a wavelength of about 6 meters (20-ft). Recall that the IRI had great sensitivity to sinusoid with a wavelength of 16 meters (wave number of 0.065 cycle/m). The figure shows that RN analysis has a low sensitivity to that wavelength and even lower sensitivity for longer wavelengths[6].

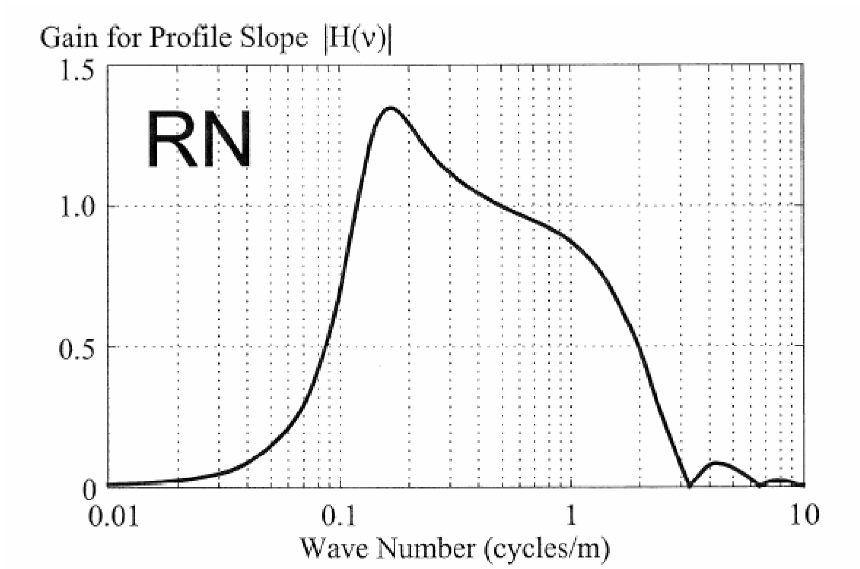


Figure 72. RN Sensitivity[6].

Based on that and the knowledge of the broader issues in vehicle dynamics, it is expected that RN proves inferior to other indices, particularly the IRI, in quantifying roughness relevant to truck ride and dynamic loads[6].

PI Background

Figure 73 shows the top view and side view of a California Profilograph. The typical testing with profilographs includes pushing the device along the pavement section. As the device, shown in figure 73, travels on the pavement section, 3 profile paths will be passed, as follows:

- The 4 left wheels travel on one path
- The 8 right wheels travel on anther path
- The recording wheel travels on a third path

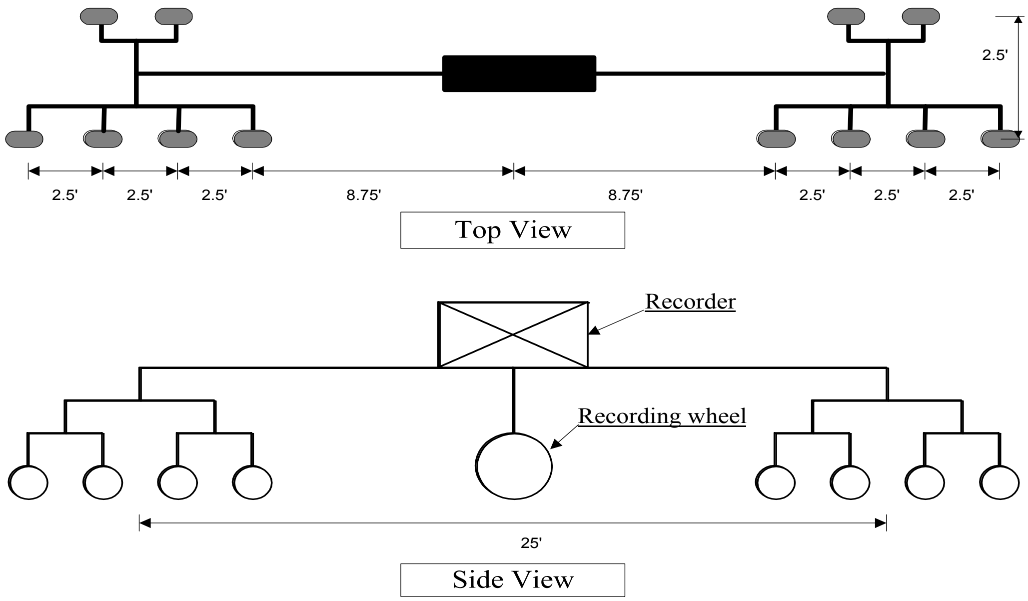


Figure 73. A Typical California Profilograph with 12 Support Wheels[7].

When the profilograph inspection is simulated using computer simulation models to calculate PI, an assumption is commonly made that the three paths have identical profiles. Compared the traces resulted by the mathematical model on the same measured profile for all wheels with the real recorded traces using the profilograph on the same pavement in[8], it reveals that both of traces are similar to each other. This assumption can be justified when the pavement has smooth lateral profiles in the width of the profilograph (approximate 2.5-ft), which is the case for new pavements.

The calculation of PI involves using a “Blanking Band”. Figure 74 shows a Profilograph Trace, the blanking band and scallops. Blanking band is a band of uniform height with its longitudinal center positioned optimally between the highs and lows of the profilograph trace depicting at least 100-ft of pavement[9] 0.2 in band height is used in computing the “Profile Index”. Scallops are the excursions of the trace above and below the blanking band[9]. The vertical maximum of a scallop must not be less than 0.03 in and the longitudinal length must be longer than 2 feet[1, 3, and 4] PI for each segment of a pavement are calculated by the following formula:

$$PI_{segment} = \frac{\sum_{j=1}^{m} \text{the maximum of absolute height in the } j^{th} \text{ scallop}}{\text{the segment length}} \quad \text{(in/mi)}$$

Recall the gain factor-Wave Length relationship presented earlier for IRI and RN, figure 75 shows this relationship for profilographs. The profilograph is a physical system that is actually close in concept to a high-pass moving average. The average is established by the many wheels, and deviations are measured relative to that average.

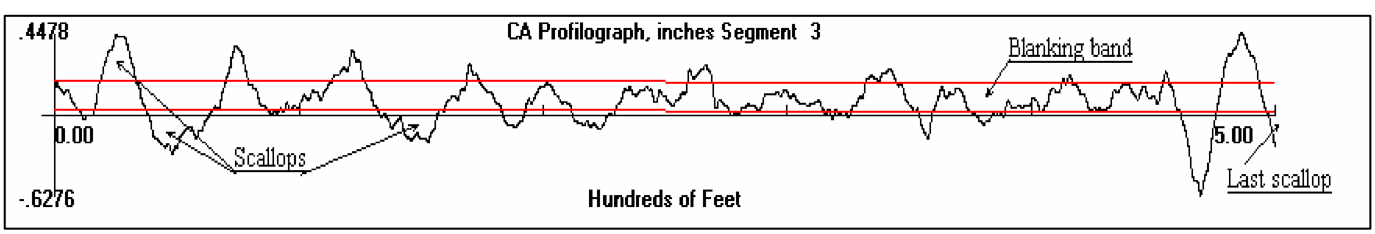


Figure 74. Profilograph Trace.

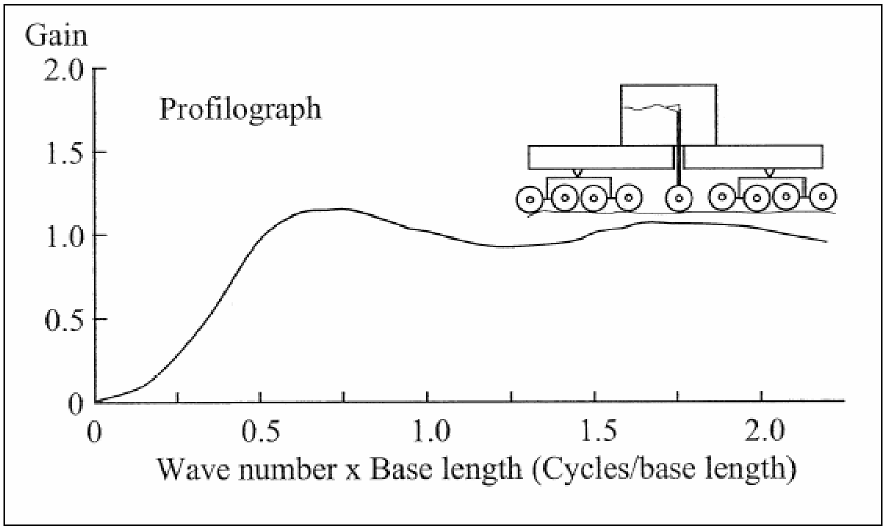


Figure 75. Profilograph Gain Factors[(5)].

RSE Background

RSE is a simplified version of profilographs. Instead of having multiple wheels, 10 wheels for California style, traveling on two paths, 2.5-ft apart, RSE has only 2 wheels at each side. Also, RSE is typically 10-ft in length, while profilograph are longer, 25-ft for the California style. The concept used in RSE and profilographs to measure the longitudinal profile is very similar. The middle wheel moves up and down along the profile indicating the division from the fixed datum, the RSE beam or the profilograph truss. The method of recording the movement of the middle wheel varies. It can be as simple as spilling water if the movement is greater than a certain value, 1/8 in, in case of NJDOT, or automated using a data logger or computer to capture the profile. Figure 76 shows a picture of NJDOT RSE. Computer simulation models can simulate the RSE inspection, as can be seen in figures 77 a, b and c. In these figures, the vertical movement of the middle wheel is calculated as a function of the rigid beam elevation, the actual middle wheel elevation and the original middle wheel elevation at a specific longitudinal position on the profile. The RSE is then moved one step and the vertical movement of the middle wheel is recalculated at the new position, as shown in figure 77.

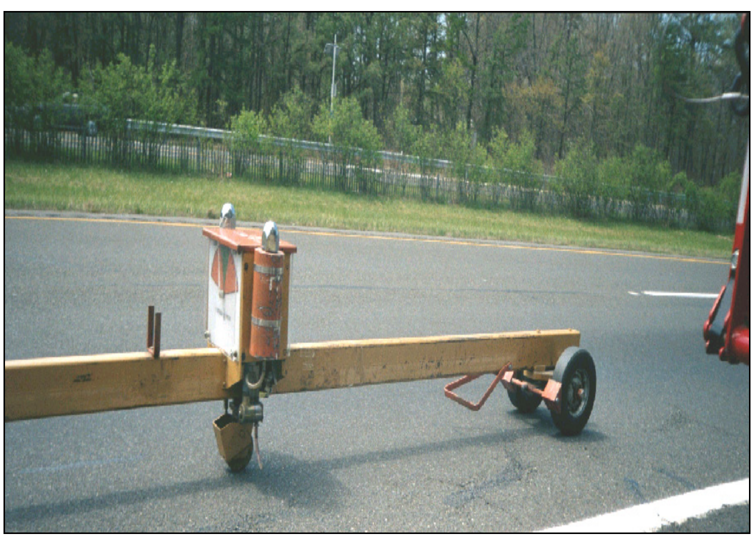
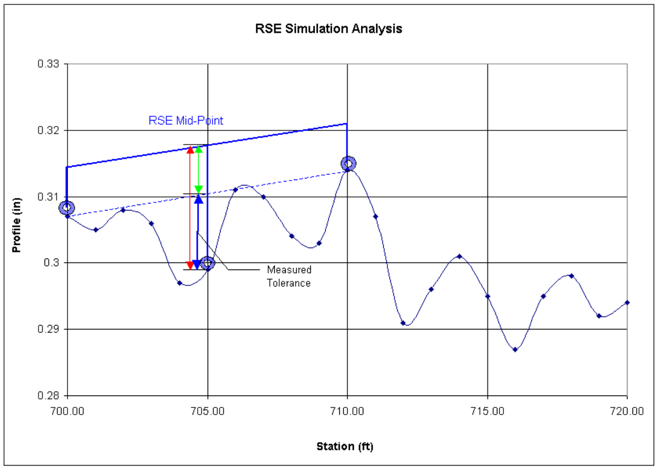
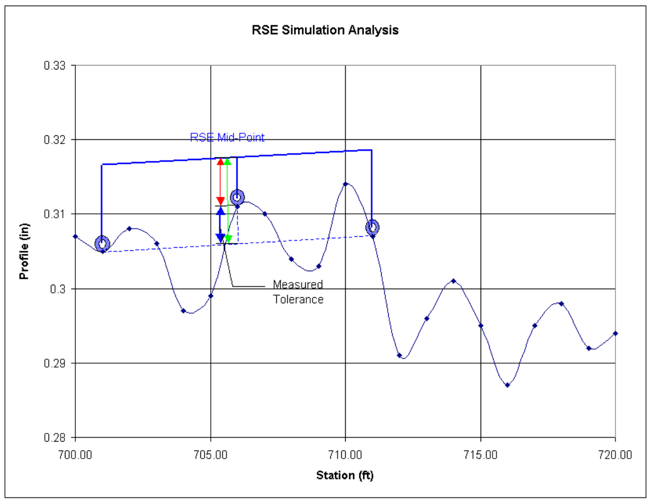


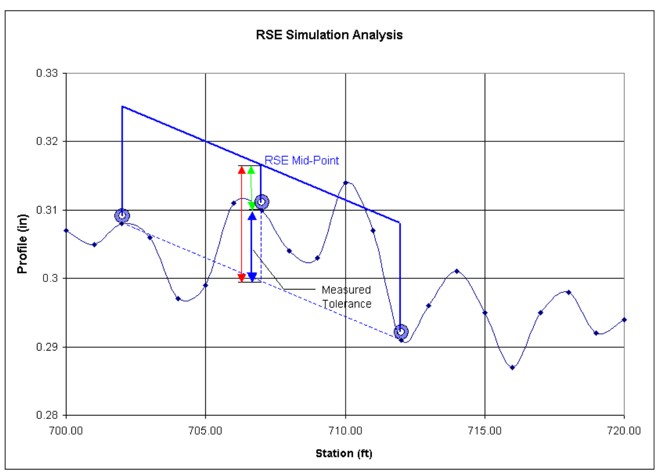
Figure 76. NJDOT RSE.



a) First Position



b) Second Position



c) Third Position

Figure 77. RSE Simulation.

Recall the gain factor-Wave Length relationship presented earlier for IRI, RN and PI, figure 78 shows this relationship for RSE. RSE has its own unique response to roughness that is different from that of profilographs, characterized by the fact that it recorded every bump three times—once when the front wheel passed over, a second time when the measuring wheel passed over, and a third time when the rear wheel passed over. Because the straightedge contacted the road surface at three points, bumps of certain wavelengths recorded at twice amplitude, while others did not record at all. Thus the rolling straightedge "tuned" to certain wavelengths of roughness in the road, while ignoring others[6].

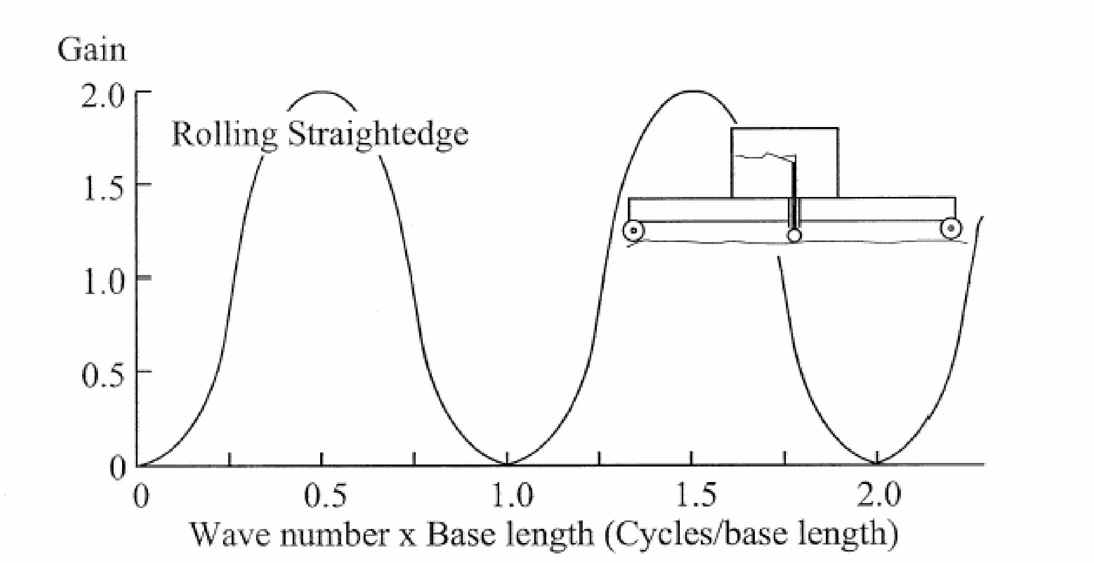


Figure 78. Profilograph Gain Factors[5].

Sample Results Traditional Ride Statistics

As discussed earlier in this section, several ride statistics are available to describe the longitudinal roughness of roads. IRI was used previously in this report to illustrate the impact of different testing parameters on the reported roughness. In this section, some of the IRI results presented in previously are reproduced in terms of RN, PI and %DL. It should be noted that RN values were calculated using RoadRuf software, PI values were calculated using Proval software and %DL was calculated using a computer simulation routine developed in Phase I of this project.

RN Sample Results

Equipment Comparisons

Figures 79 to 81 show samples of the RN calculated using the profiles measured using all the devices participated in this study. These figures are for a very smooth section (Route 55), smooth section (Route 195) and relatively rough section (Route 18), respectively. These figures indicate there are some variability among devices. This variability increases for rougher sections. As can be seen from these figures, the maximum variability of RN for the very smooth section, figure 79, is about 1.5. The corresponding numbers for the smooth, figure 80, and relatively rough, figure 81, sections are about 2.5 and 3.5, respectively.

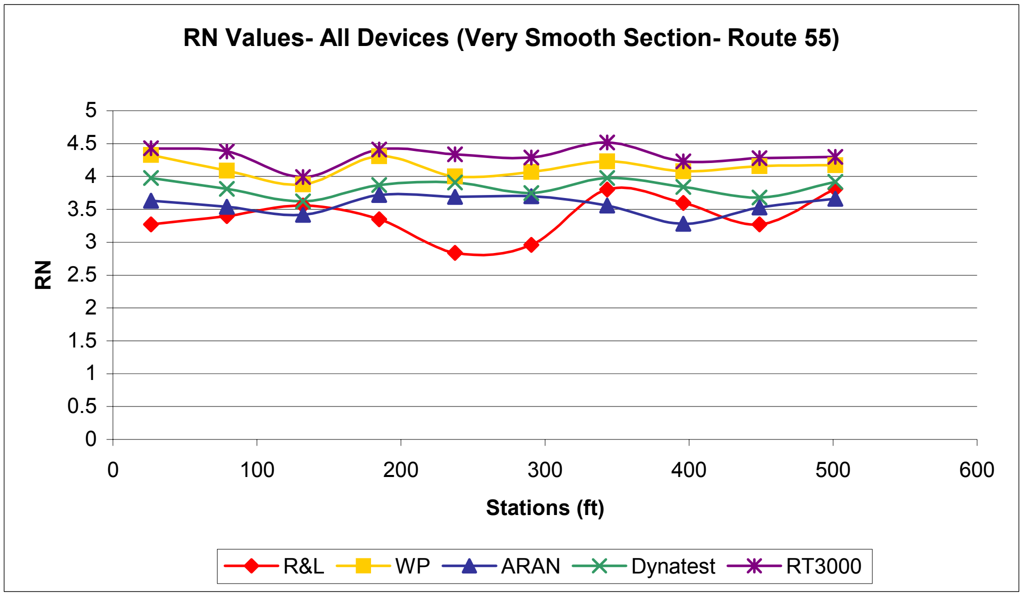


Figure 79. RN Values – All Devices (Very Smooth Section – Route 55).

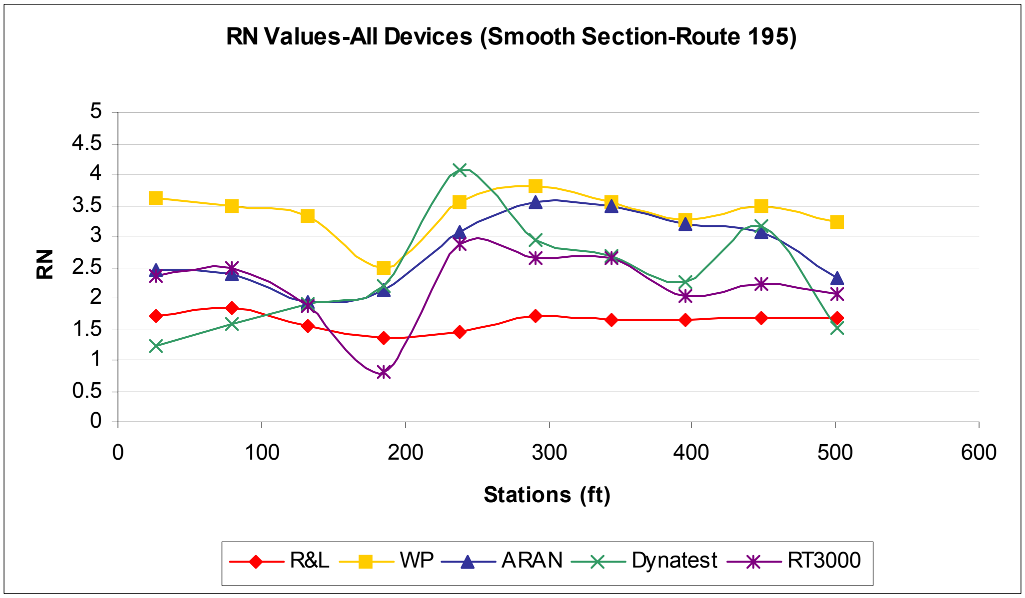


Figure 80. RN Values – All Devices (Smooth Section – Route 195).

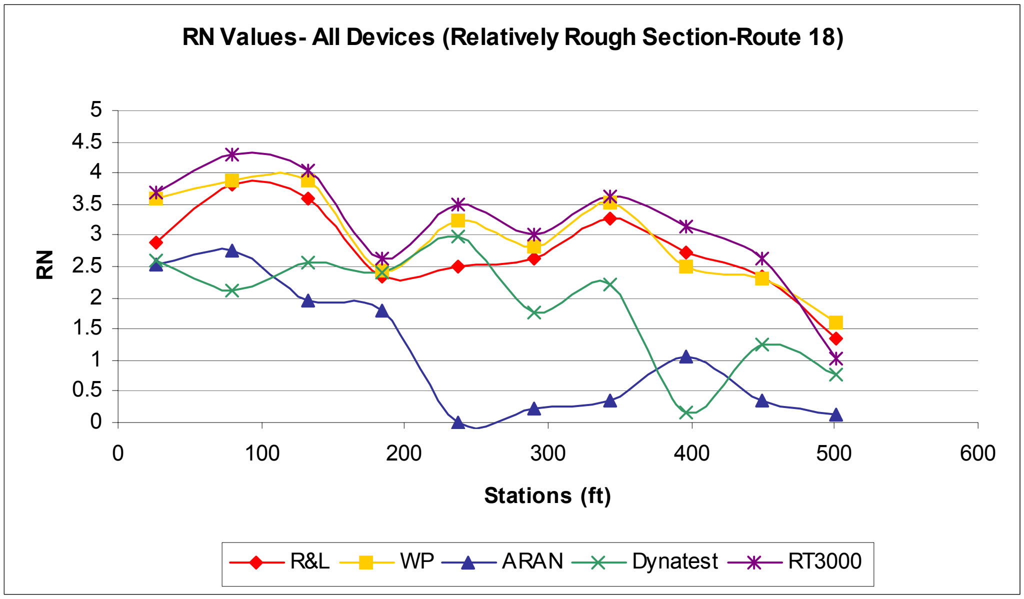


Figure 81. RN Values – All Devices (Relatively Rough Section – Route 18).

Speed Effect

As in the case of IRI presented earlier, the speed dependency of each high-speed profiler in terms of RN was investigated. Multiple speed runs were performed by each of the high-speed profilers to evaluate the speed dependency of the device. The measured profiles were then filtered and processed using RoadRuf to calculate RN at different speeds. Samples of these results for a very smooth section (Route 55), smooth section (Route 195) and relatively rough section (Route 18) are shown in figures 82 to 90. In general, RN is not as sensitive to speed compared to IRI, because of the maximum range of 0-5. As shown in table 13a, the differences due to speed except for ARAN are less than 1.0 for the very smooth section. For the smooth section, maximum difference due to changes in speed ranges from 1.28-1.75 for Dynatest, 1.6-2.0 and 1.38-1.9 for ARAN and ICC RT3000, respectively. In general Dynatest shows the least RN sensitivity to speed and ARAN the most. Table 13b shows the average and standard deviation for the speed effect on the high-speed profilers. In general, Dynatest shows the least effect while ARAN shows the highest.

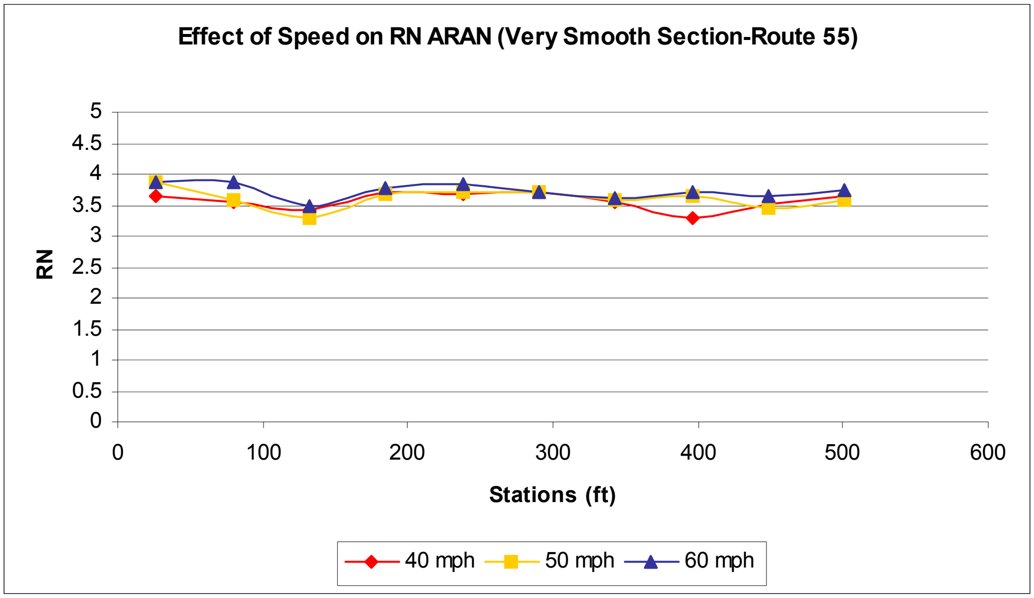


Figure 82. Effect of Speed on RN - ARAN (Very Smooth Section – Route 55).

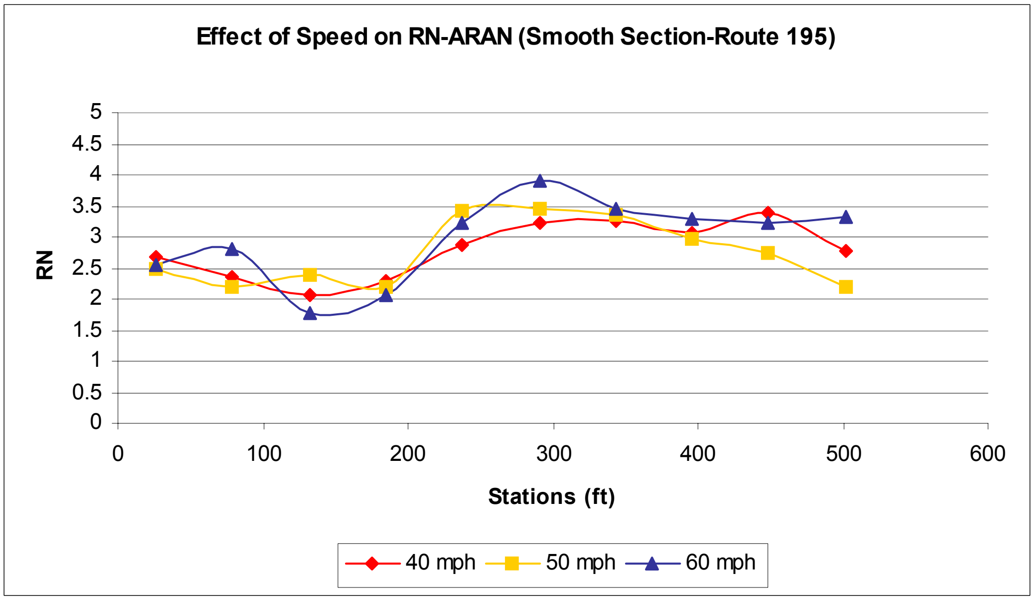


Figure 83. Effect of Speed on RN - ARAN (Smooth Section – Route 195).

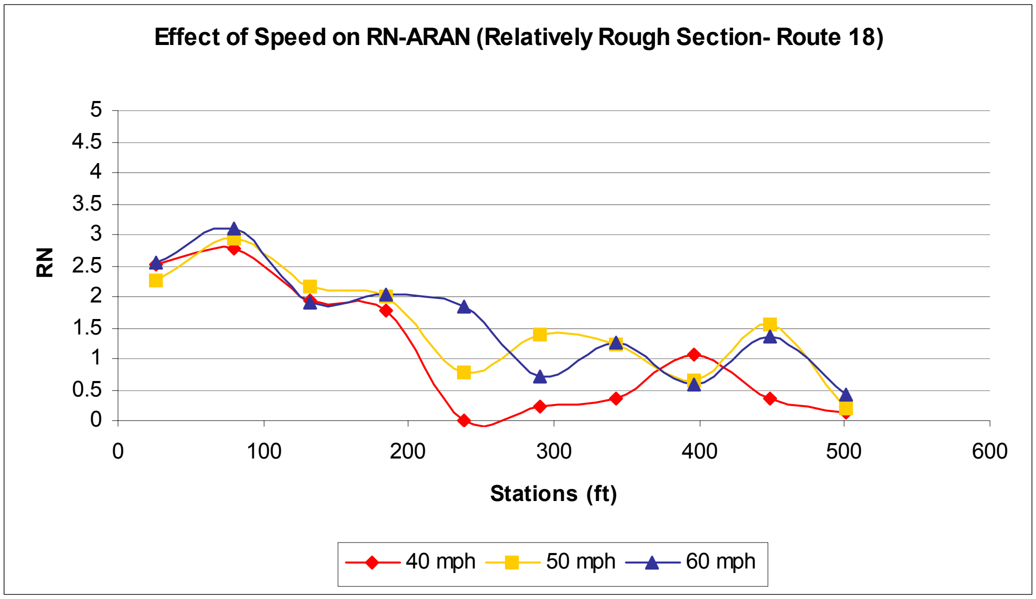


Figure 84. Effect of Speed on RN - ARAN (Relatively Rough Section – Route 18).

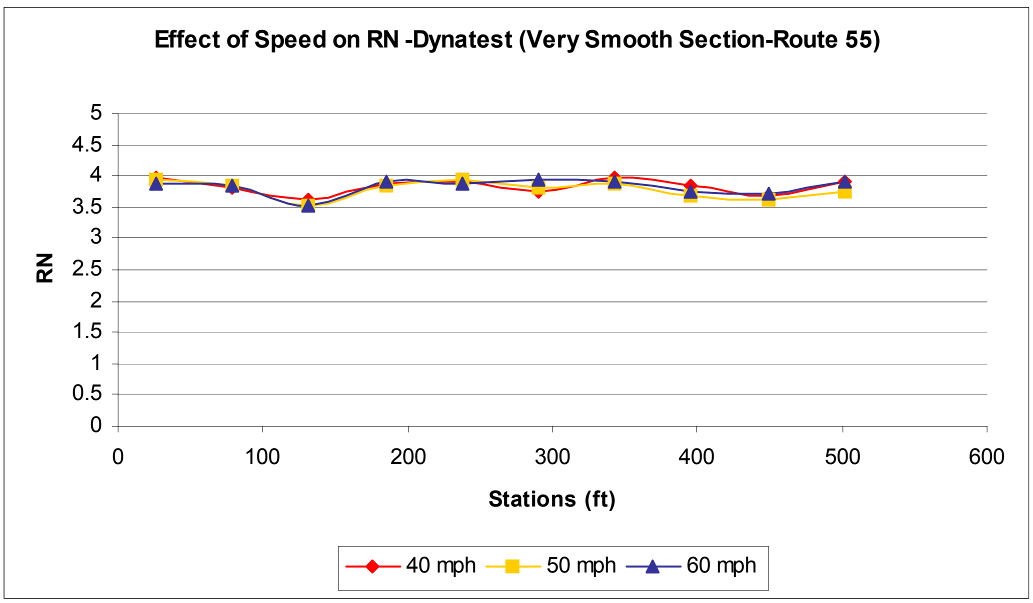


Figure 85. Effect of Speed on RN - Dynatest (Very Smooth Section – Route 55).

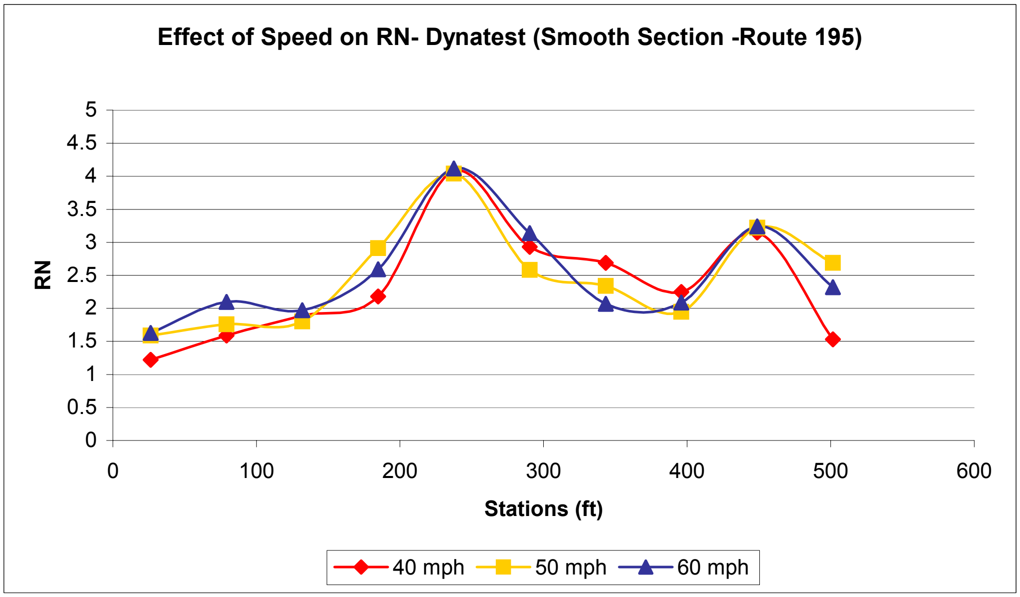


Figure 86. Effect of Speed on RN - Dynatest (Smooth Section – Route 195).

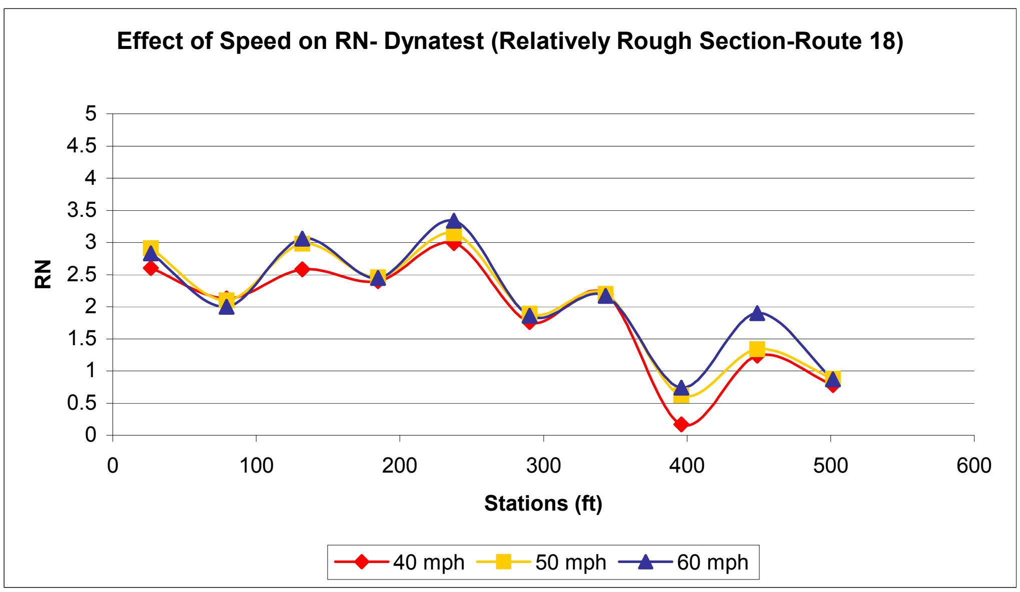


Figure 87. Effect of Speed on RN - Dynatest (Relatively Rough Section – Route 18)

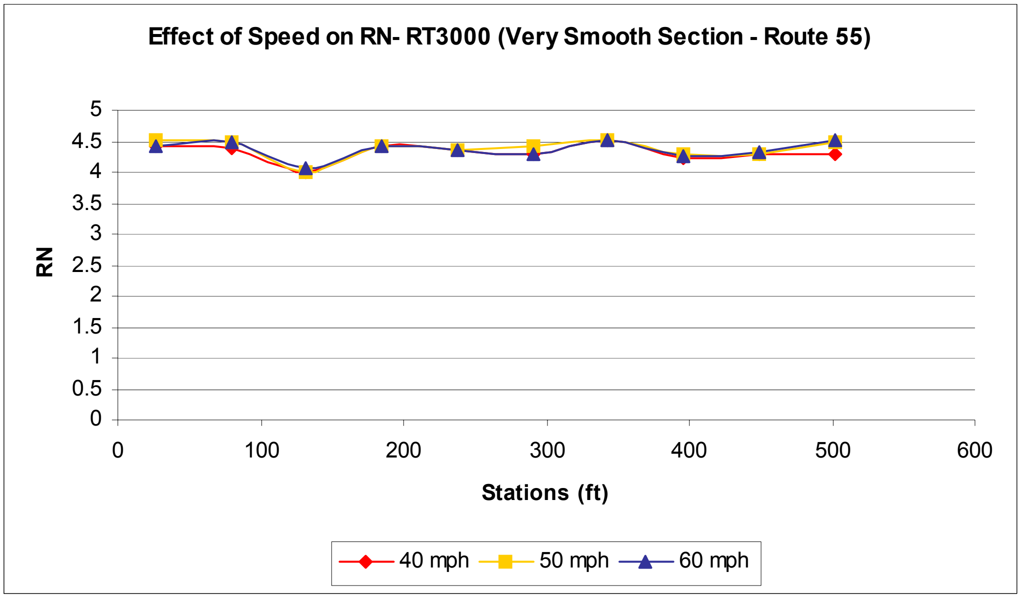


Figure 88. Effect of Speed on RN - RT3000 (Very Smooth Section – Route 55).

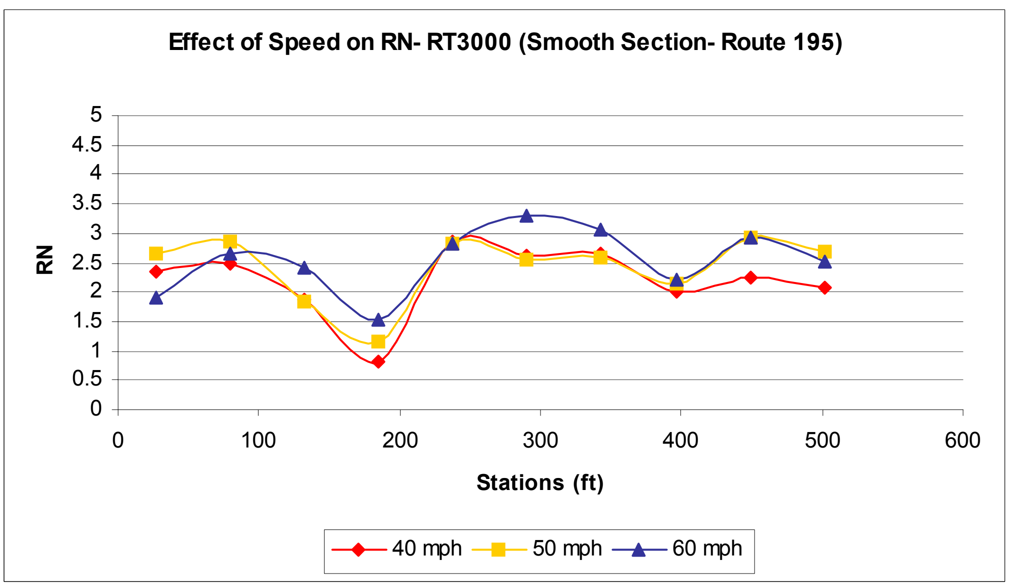


Figure 89. Effect of Speed on RN - RT3000 (Smooth Section – Route 195).

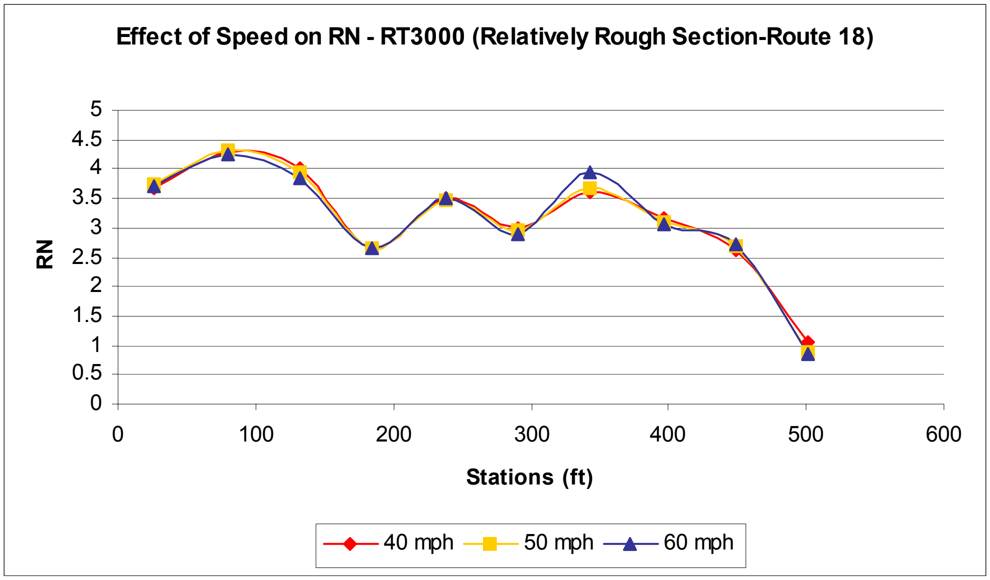


Figure 90. Effect of Speed on RN - RT3000 (Relatively Rough Section – Route 18).

Table 13a. Maximum Speed Effect on RN for 52.8-ft Sub-sections.

Route 195 (smooth)	RN40-RN50	RN40-RN60	RN50-RN60
ARAN	1.65	1.6	2.0
RT3000	1.9	1.76	1.38
Dynatest	1.28	1.51	1.75
Route 55 (very smooth)	**RN40-RN50**	**RN40-RN60**	**RN50-RN60**
ARAN	0.48	0.55	2.06
RT3000	0.97	0.96	0.55
Dynatest	0.88	0.58	0.48

Table 13b. Average and Standard Deviation Speed Effect on RN for 52.8-ft Sub-sections.

	RN40-RN50		RN40-RN60		RN50-RN60	
Route 55 (very smooth)	**Average**	**Std. Dev**	**Average**	**Std. Dev**	**Average**	**Std. Dev**
ARAN	0.123	0.1071	0.1384	0.1045	0.1348	0.1713
RT3000	0.07	0.094	0.073	0.09	0.063	0.067
Dynatest	0.0876	0.0965	0.0874	0.0815	0.0682	0.0601
	RN40-RN50		**RN40-RN60**		**RN50-RN60**	
Route 195 (smooth)	**Average**	**Std. Dev**	**Average**	**Std. Dev**	**Average**	**Std. Dev**
ARAN	0.32	0.3123	0.3509	0.294	0.3853	0.3652
RT3000	0.298	0.302	0.321	0.297	0.234	0.260
Dynatest	0.314	0.3016	0.2917	0.2767	0.3721	0.3619

Filtering Effects

The effect of filtering on RN was also investigated using the RoadRuf. Moving average filters with different base lengths, combinations of low pass and high pass filter options, were applied to the R&L, WP and RT3000 raw unfiltered profiles. Profiles from ARAN and Dynatest were not considered in this exercise, because they were already filtered during the data collection. The following filter combinations were investigated:

- Low pass (LP) filters of 1, 2 and 3 ft
- High pass (HP) filters of 100, 200, and 300 ft
- Band filters (BF) of 1-300, 2-300, and 3-300

Similar trend to that of IRI in which band filtering results in the most significant differences from the unfiltered was also observed for RN. However, WP instead of R&L (as is the case for IRI) is the least sensitive to filtering.

Samples of these results for very smooth (Route 55), smooth (Route 195) and relatively rough sections (Route 18) are shown in figures 91 to 99. It should be noted that HP filtering doesn't result in significant differences, causing the curves to overlap, figures 91b, 92b, 93b, 94b, 95b, 96b, 97b, 98b and 99b. A summary of the maximum differences between unfiltered and filtered RN values (excluding the first subsection) is shown in table 14. The magnitude of the differences from the unfiltered varies with roughness class, but RN is not as sensitive to filters as IRI.

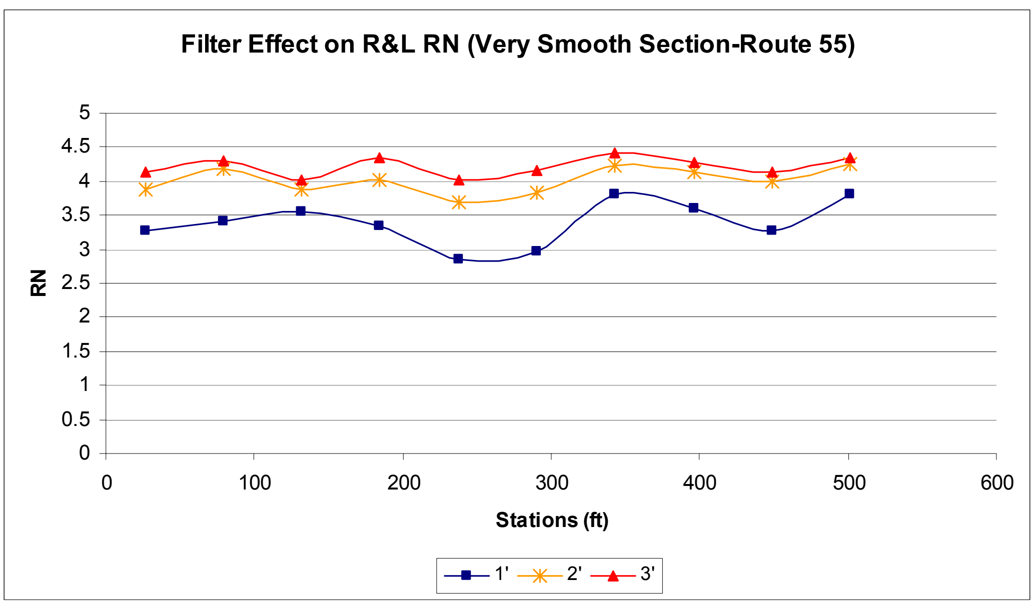


Figure 91a. Filter Effect on R&L RN (Very Smooth Section - Route 55).

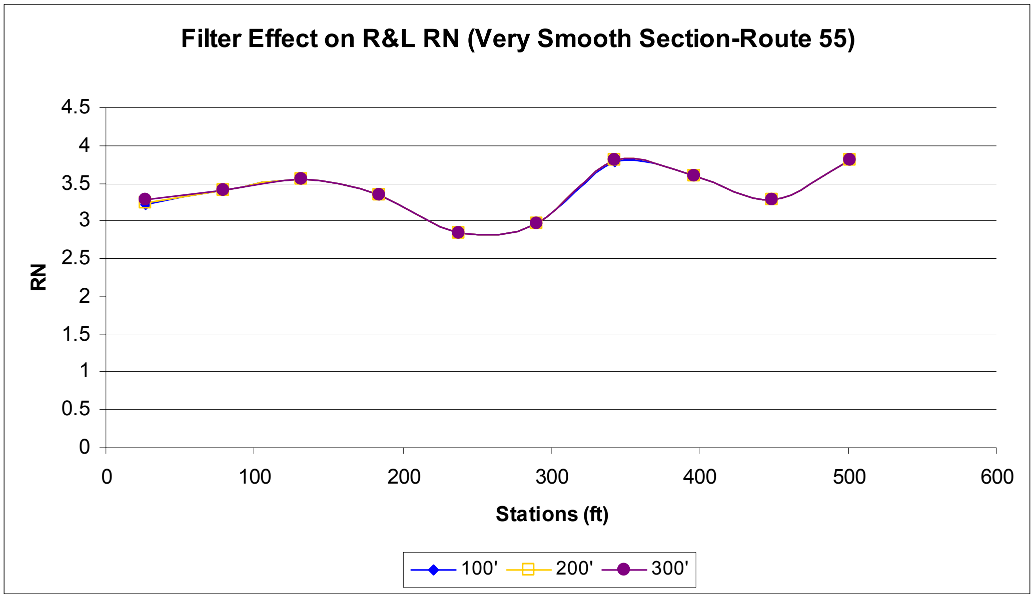


Figure 91b. Filter Effect on R&L RN (Very Smooth Section - Route 55).

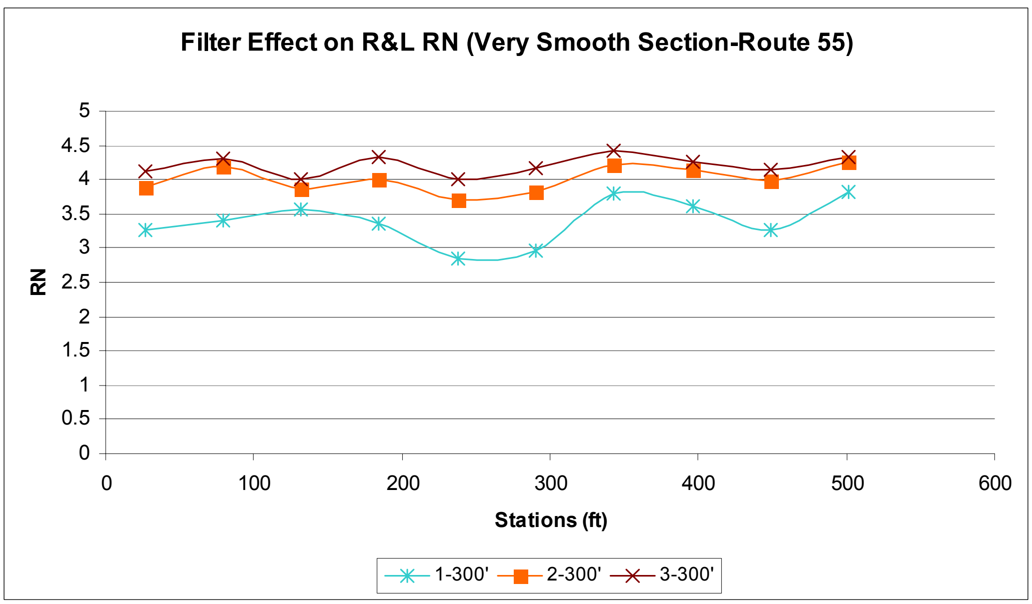


Figure 91c. Filter Effect on R&L RN (Very Smooth Section - Route 55).

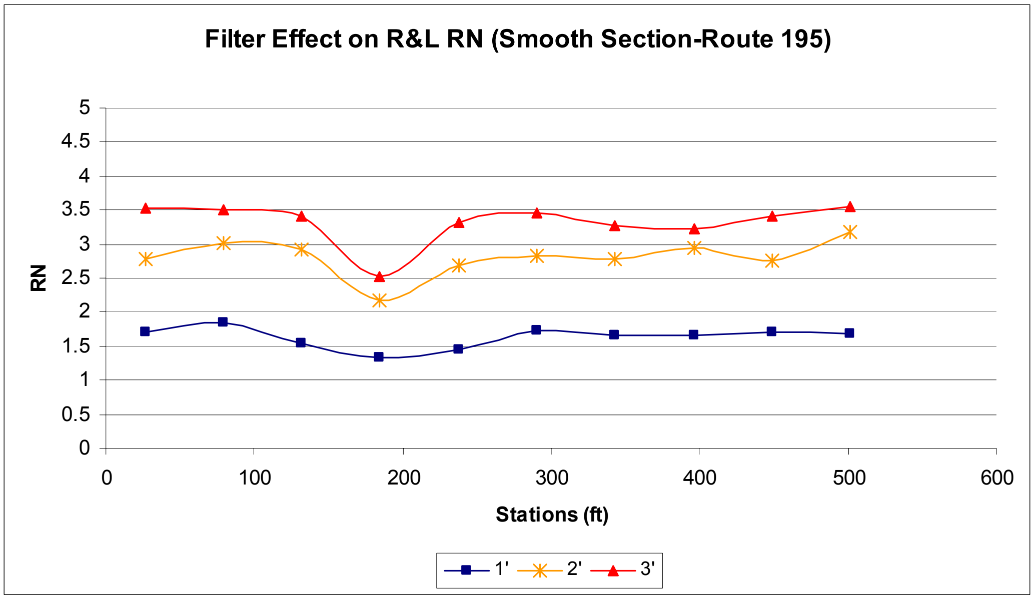


Figure 92a. Filter Effect on R&L RN (Smooth Section - Route 195).

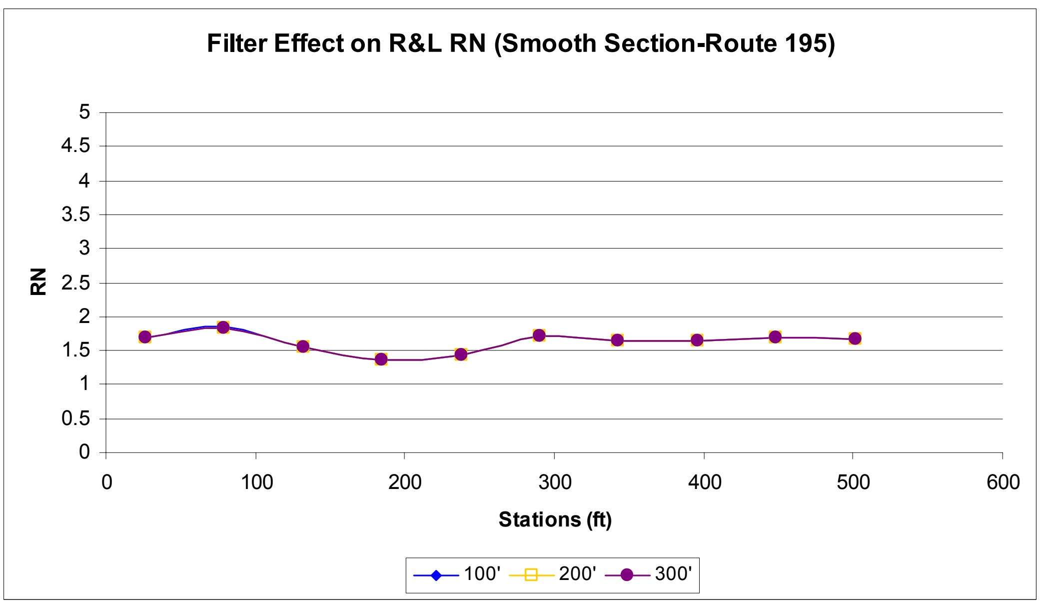


Figure 92b. Filter Effect on R&L RN (Smooth Section - Route 195).

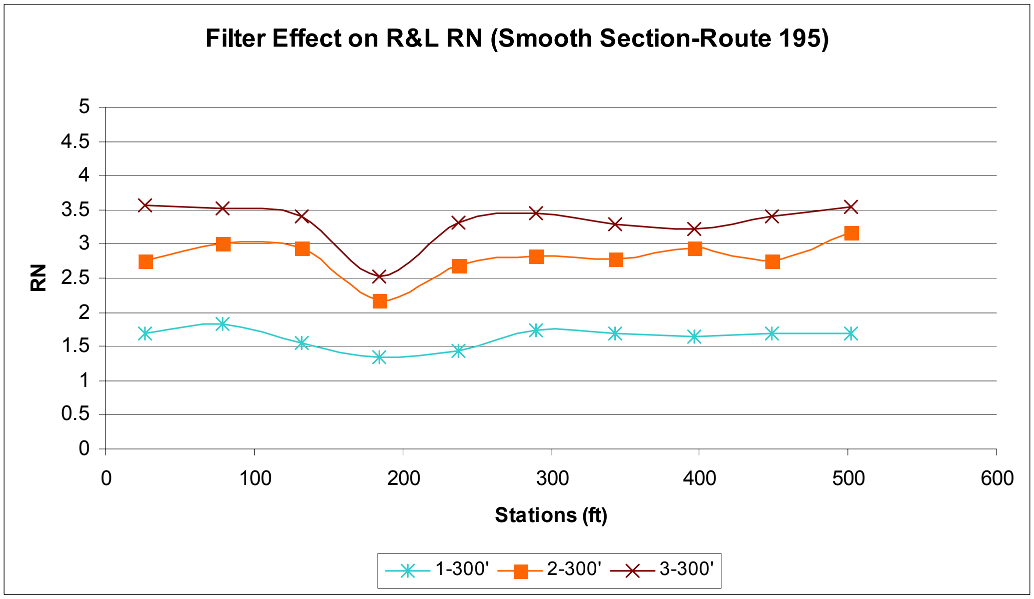


Figure 92c. Filter Effect on R&L RN (Smooth Section - Route 195).

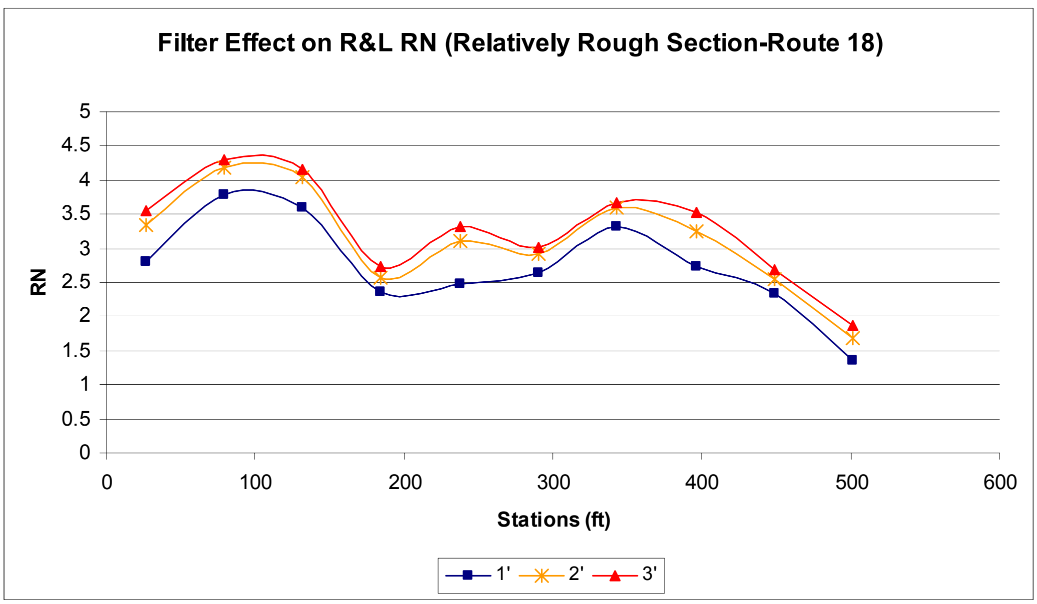


Figure 93a. Filter Effect on R&L RN (Relatively Rough Section - Route 18).

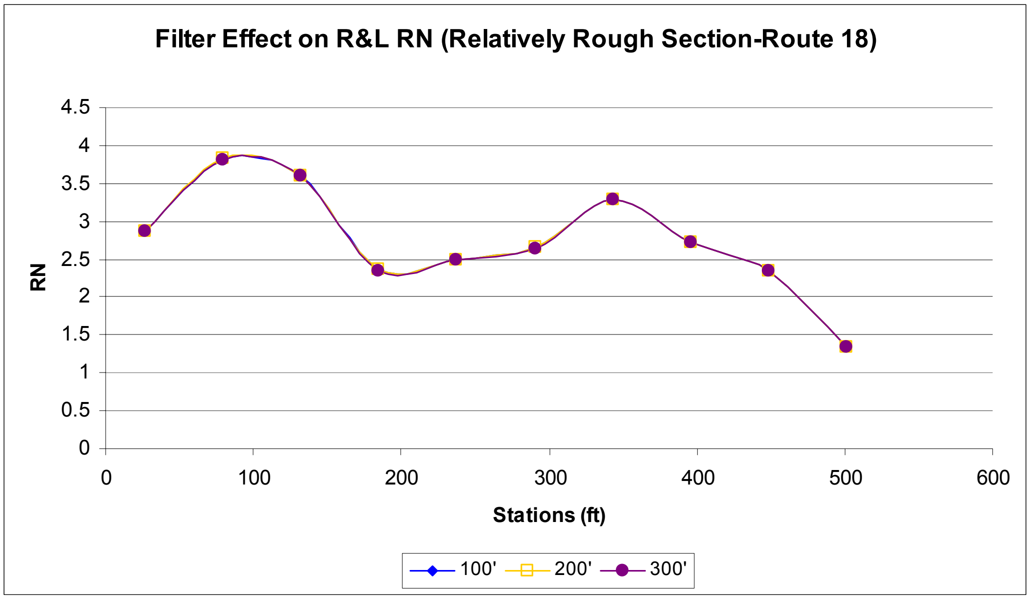


Figure 93b. Filter Effect on R&L RN (Relatively Rough Section - Route 18).

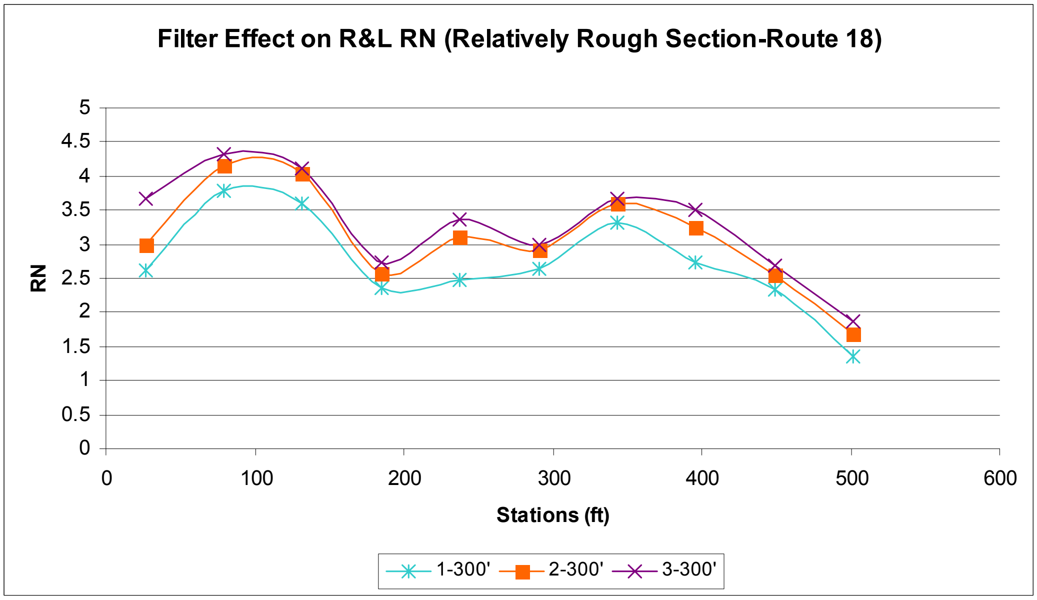


Figure 93c. Filter Effect on R&L RN (Relatively Rough Section - Route 18).

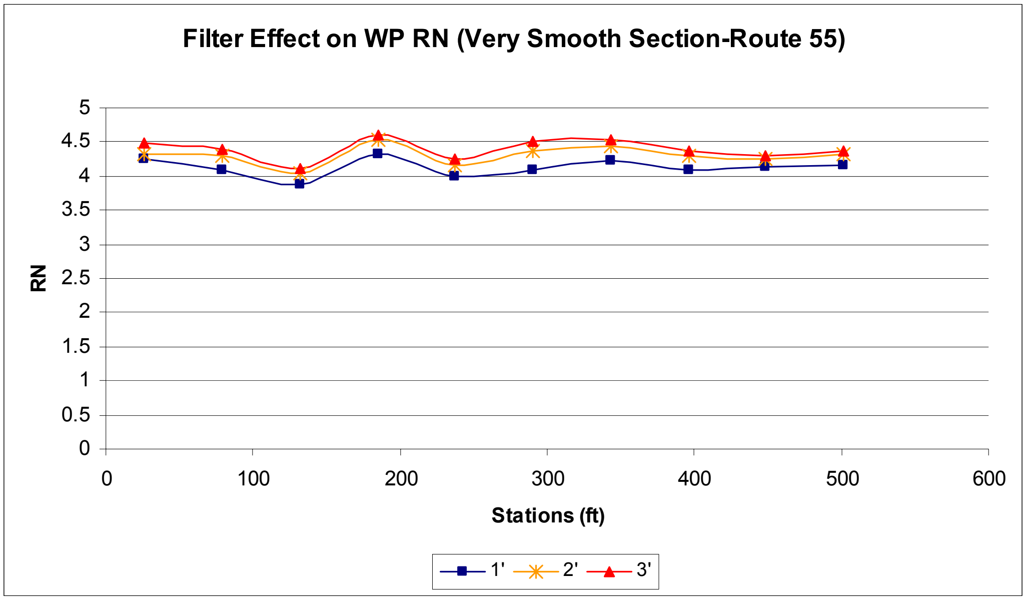


Figure 94a. Filter Effect on WP RN (Very Smooth Section - Route 55).

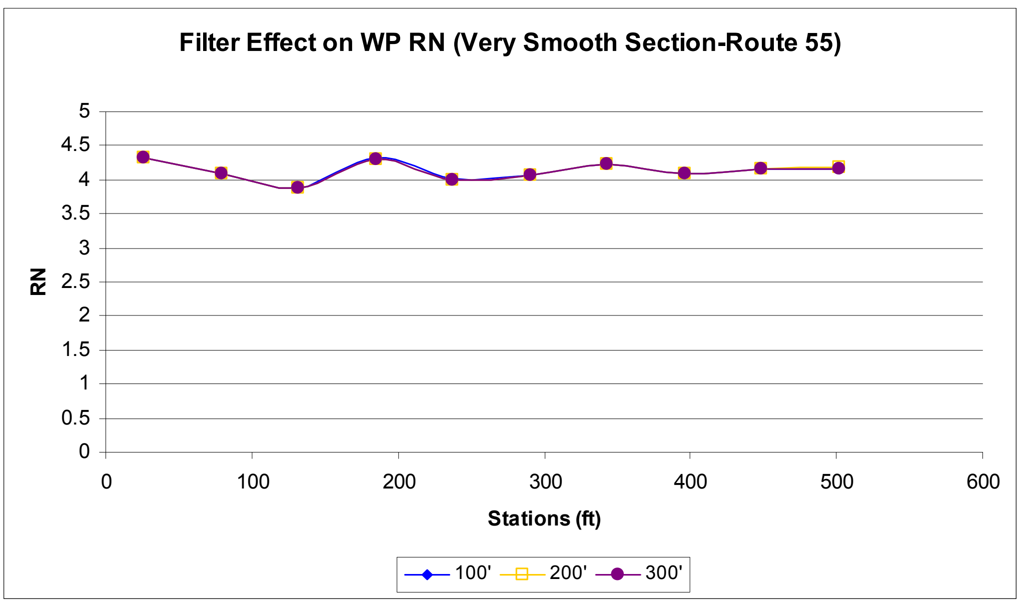


Figure 94b. Filter Effect on WP RN (Very Smooth Section - Route 55).

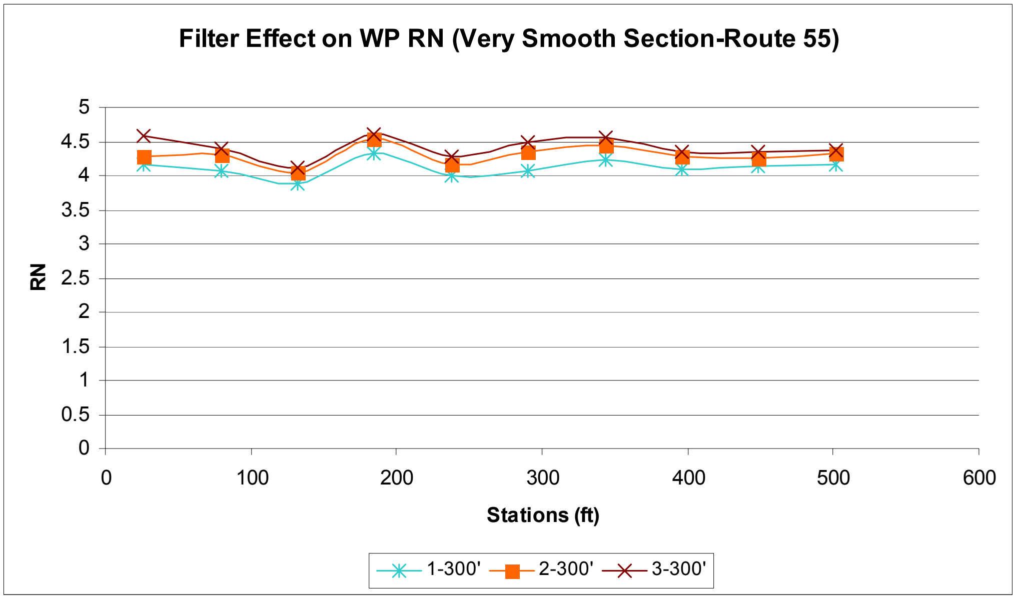


Figure 94c. Filter Effect on WP RN (Very Smooth Section - Route 55).

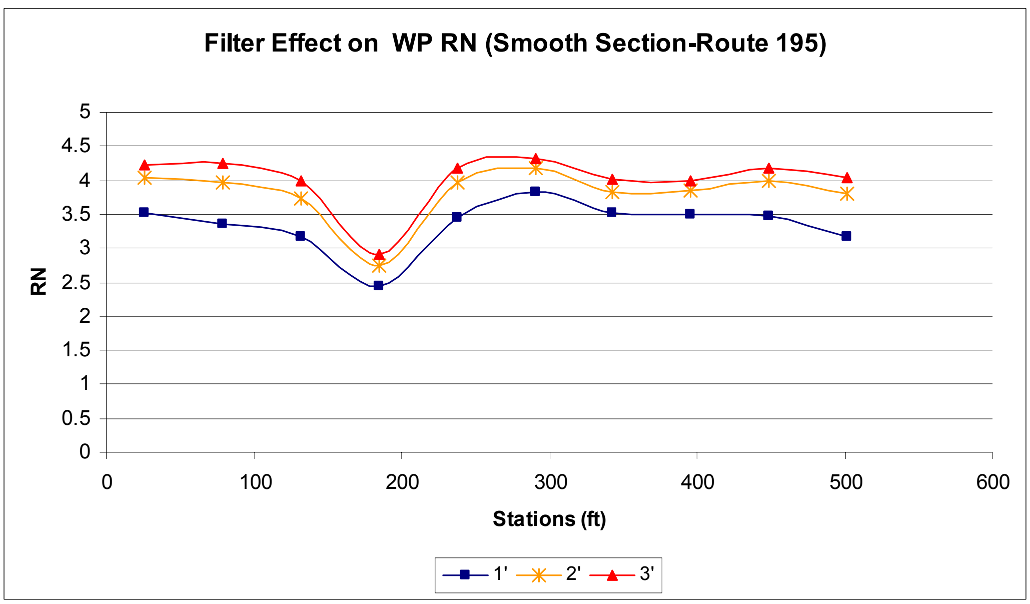


Figure 95a. Filter Effect on WP RN (Smooth Section - Route 195).

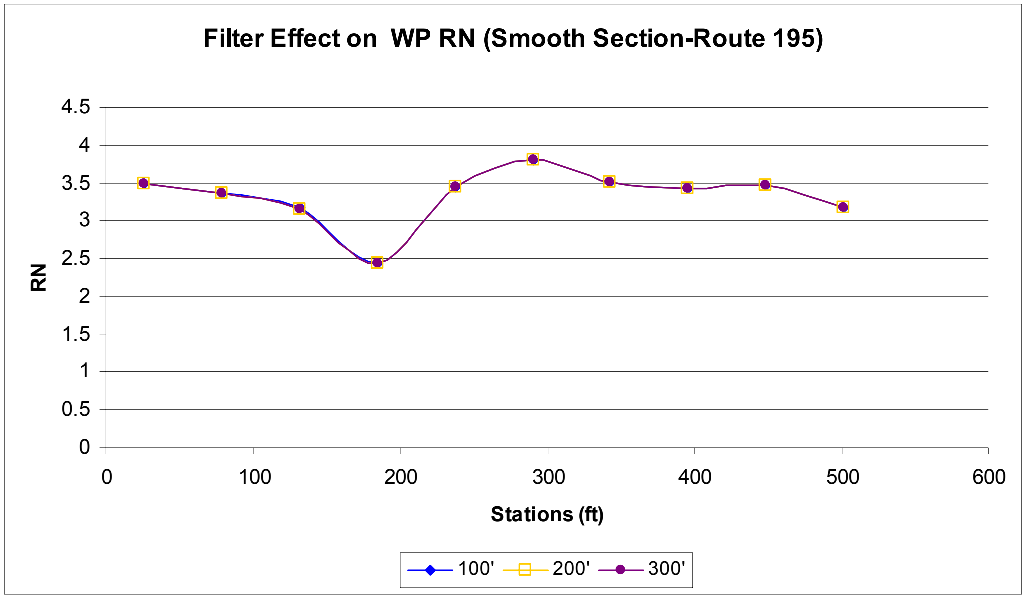


Figure 95b. Filter Effect on WP RN (Smooth Section - Route 195).

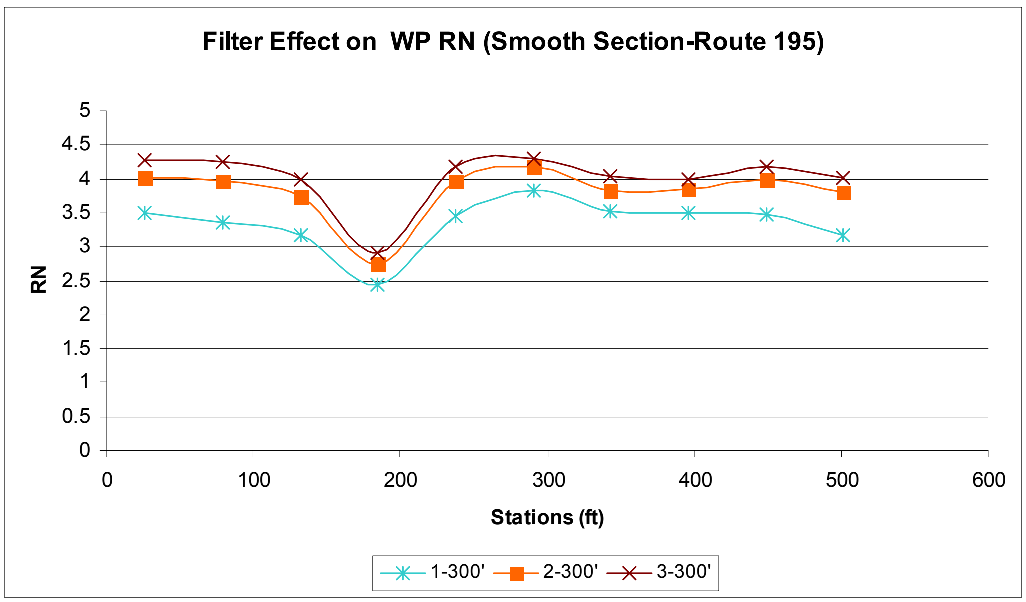


Figure 95c. Filter Effect on WP RN (Smooth Section - Route 195).

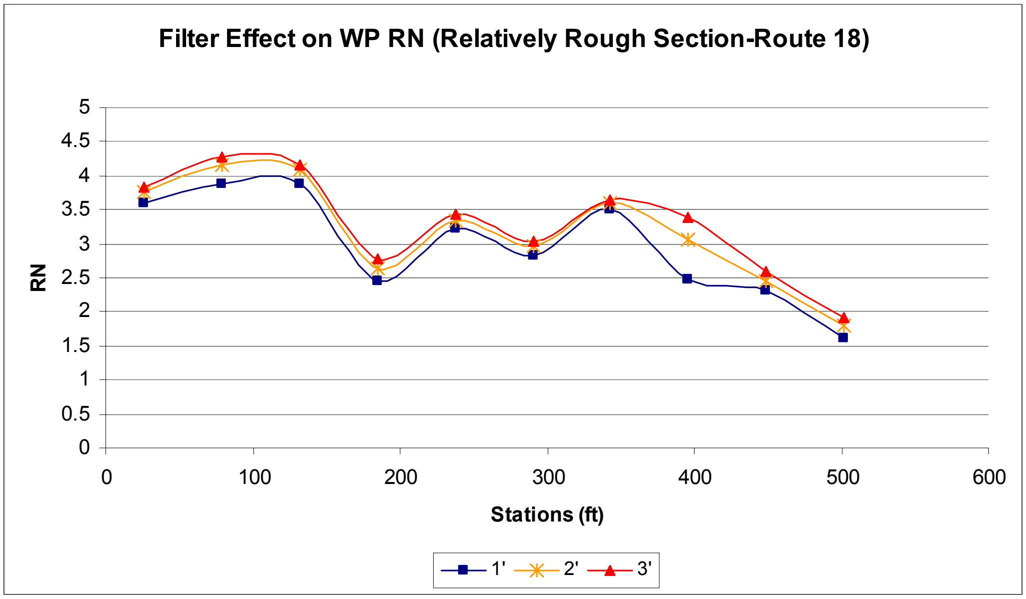


Figure 96a. Filter Effect on WP RN (Relatively Rough Section - Route 18).

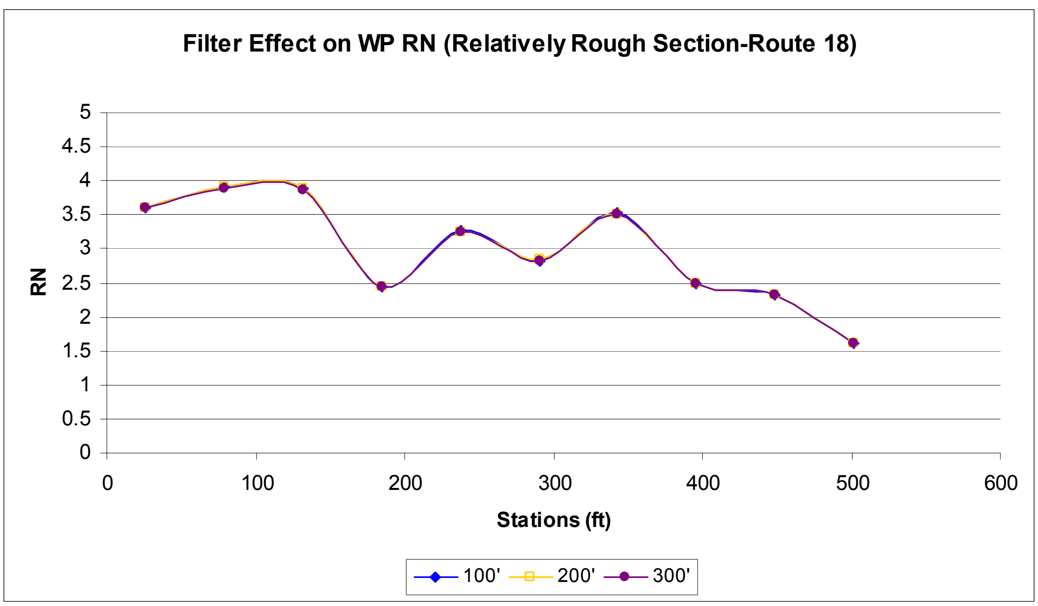


Figure 96b. Filter Effect on WP RN (Relatively Rough Section - Route 18).

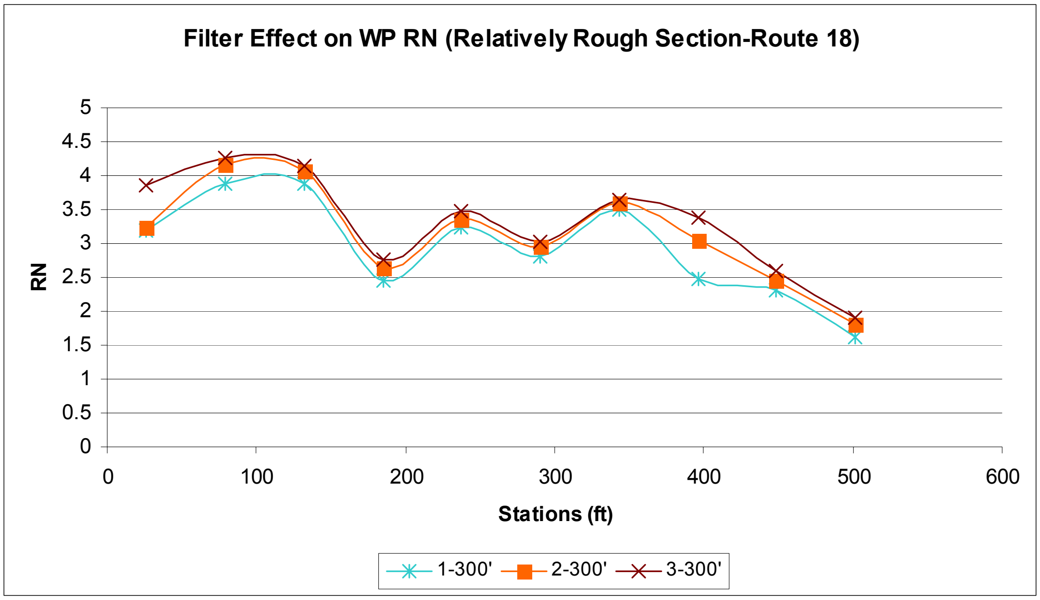


Figure 96c. Filter Effect on WP RN (Relatively Rough Section - Route 18).

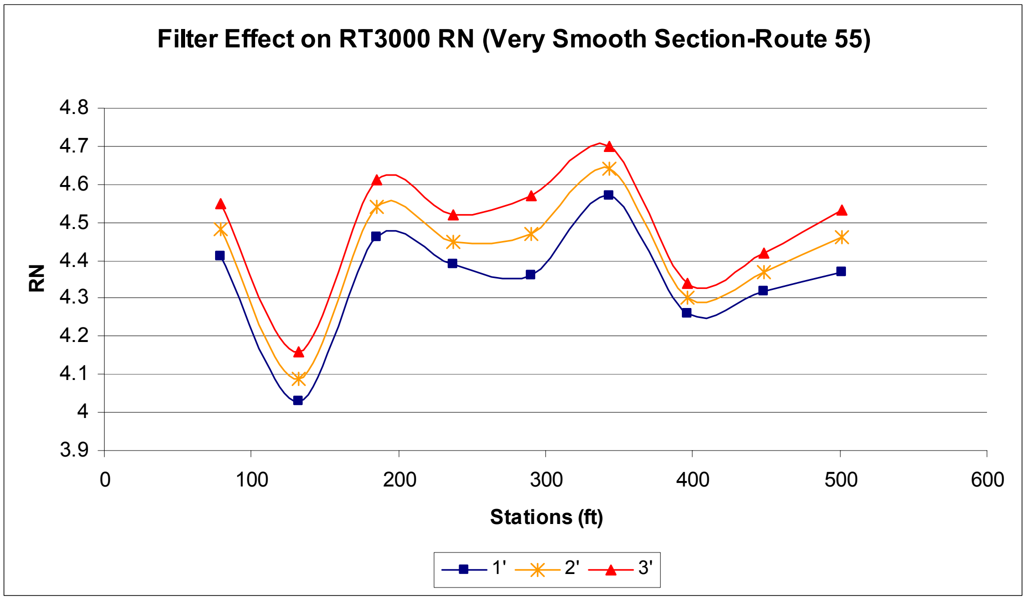


Figure 97a. Filter Effect on RT3000 RN (Very Smooth Section - Route 55).

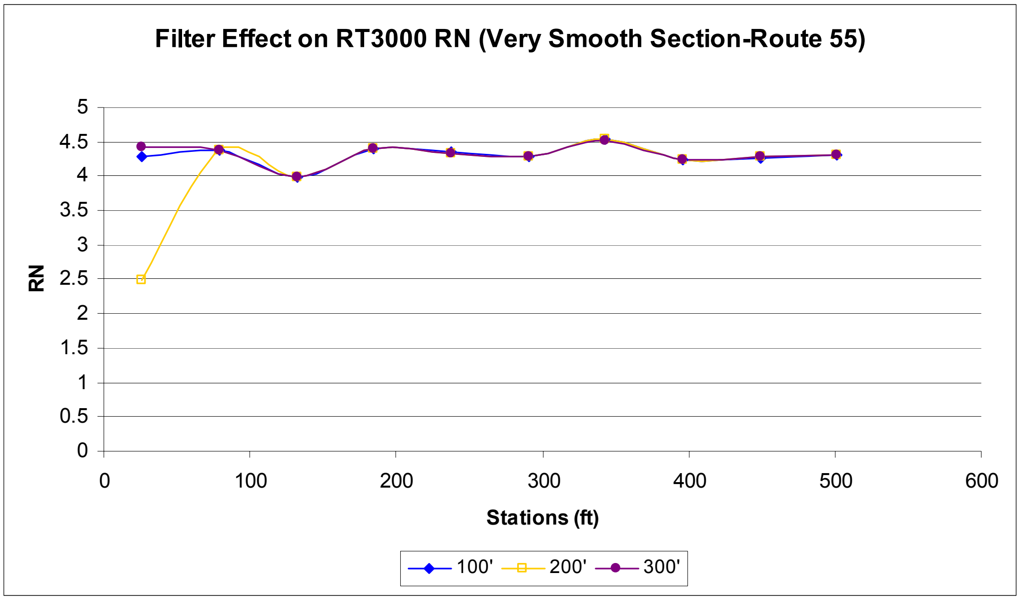


Figure 97b. Filter Effect on RT3000 RN (Very Smooth Section - Route 55).

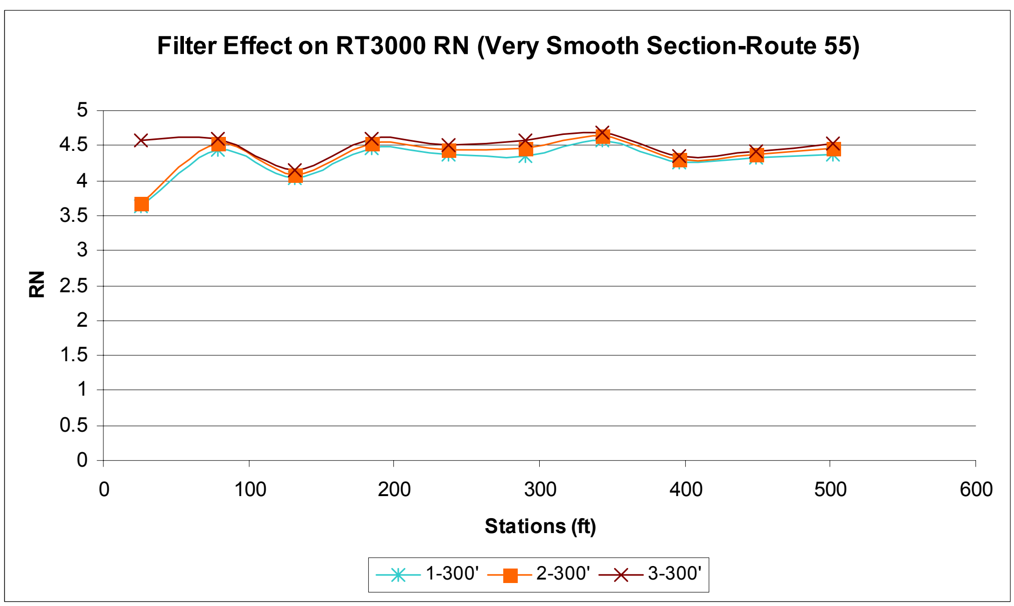


Figure 97c. Filter Effect on RT3000 RN (Very Smooth Section - Route 55).

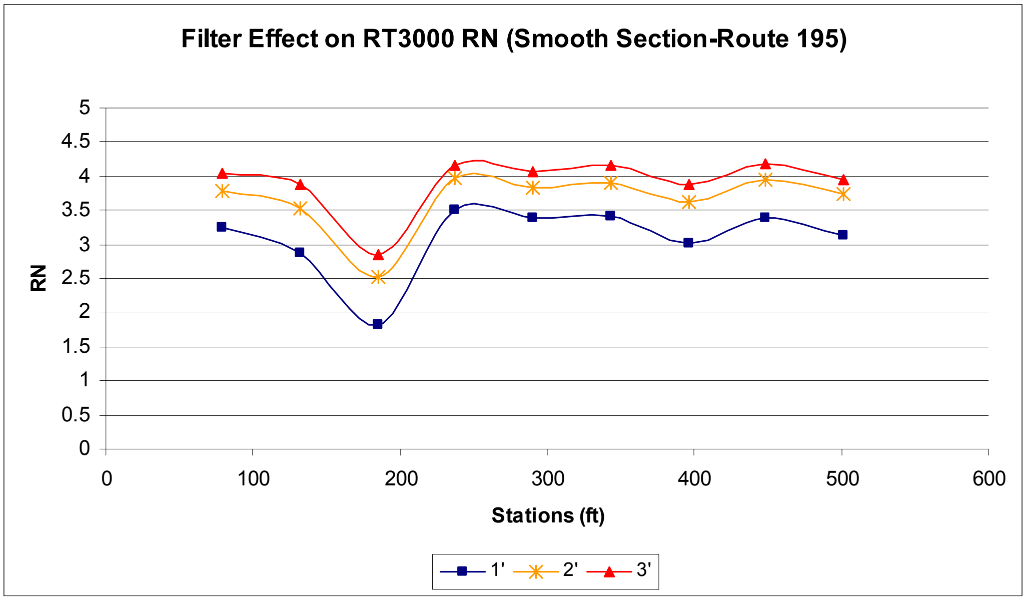


Figure 98a. Filter Effect on RT3000 RN (Smooth Section - Route 195).

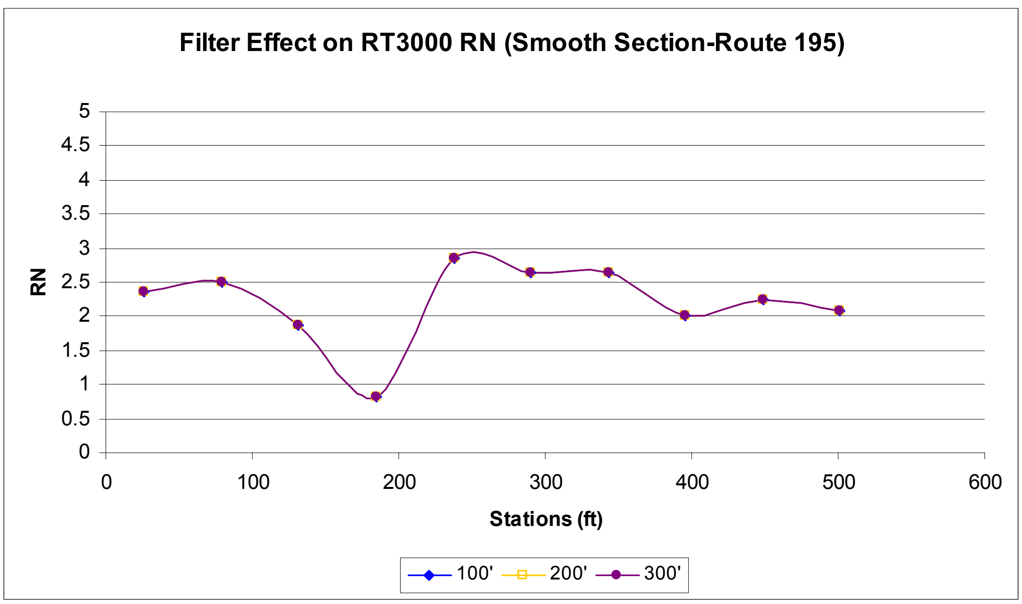


Figure 98b. Filter Effect on RT3000 RN (Smooth Section - Route 195).

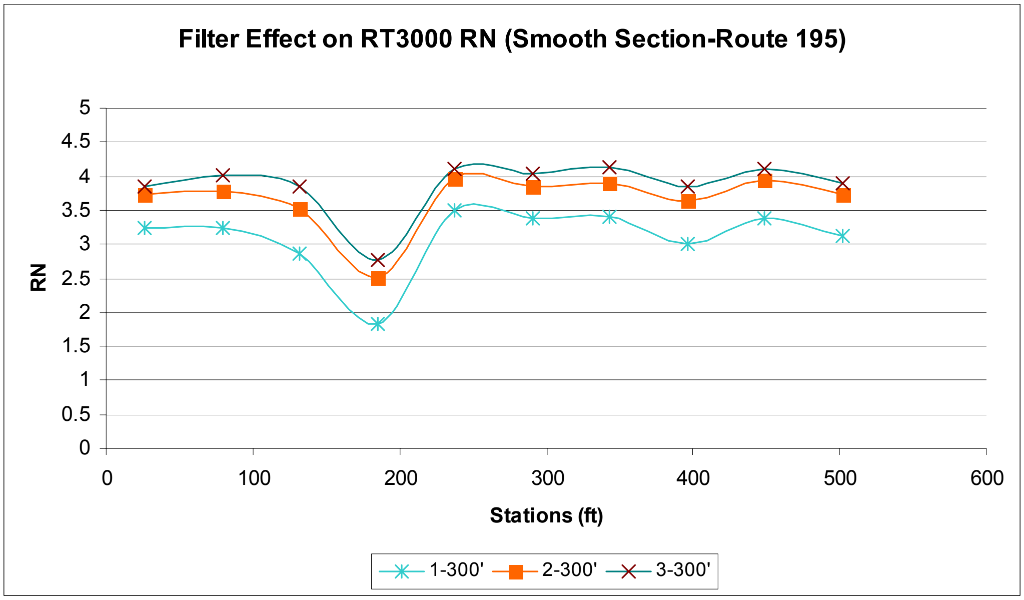


Figure 98c. Filter Effect on RT3000 RN (Smooth Section - Route 195).

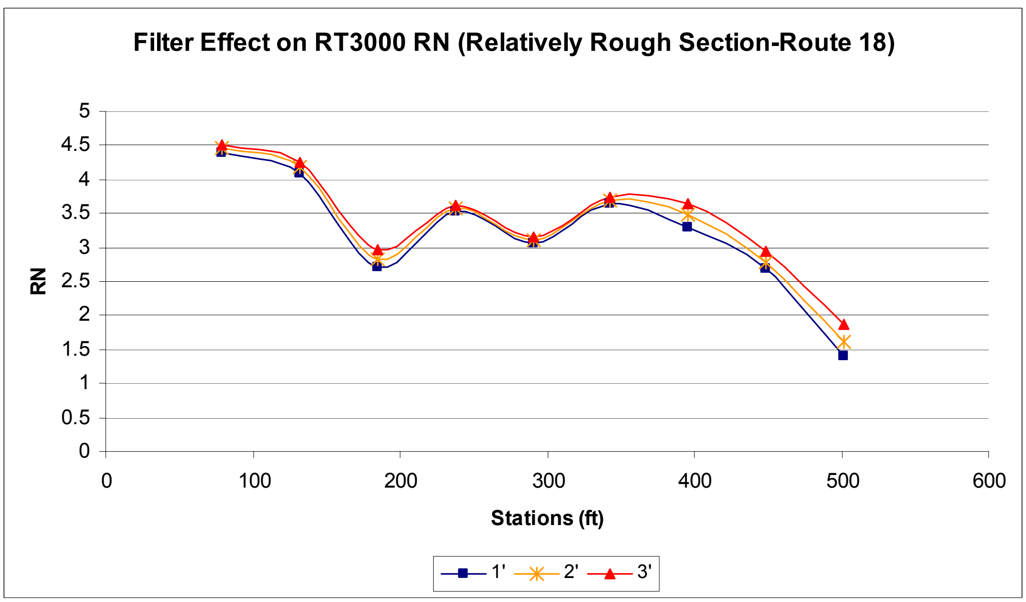


Figure 99a. Filter Effect on RT3000 - RN (Relatively Rough Section - Route 18).

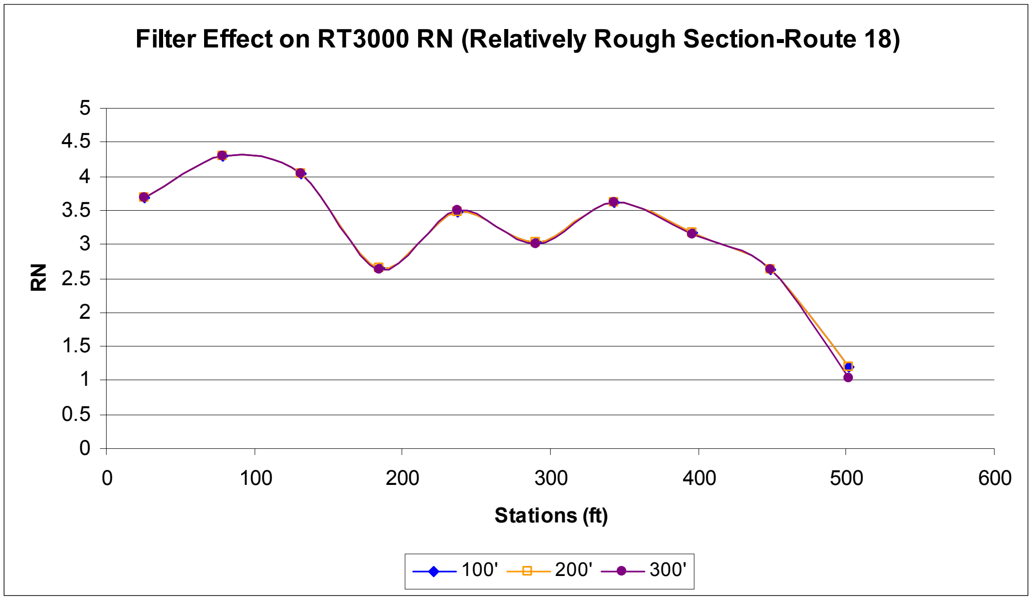


Figure 99b. Filter Effect on RT3000 - RN (Relatively Rough Section - Route 18).

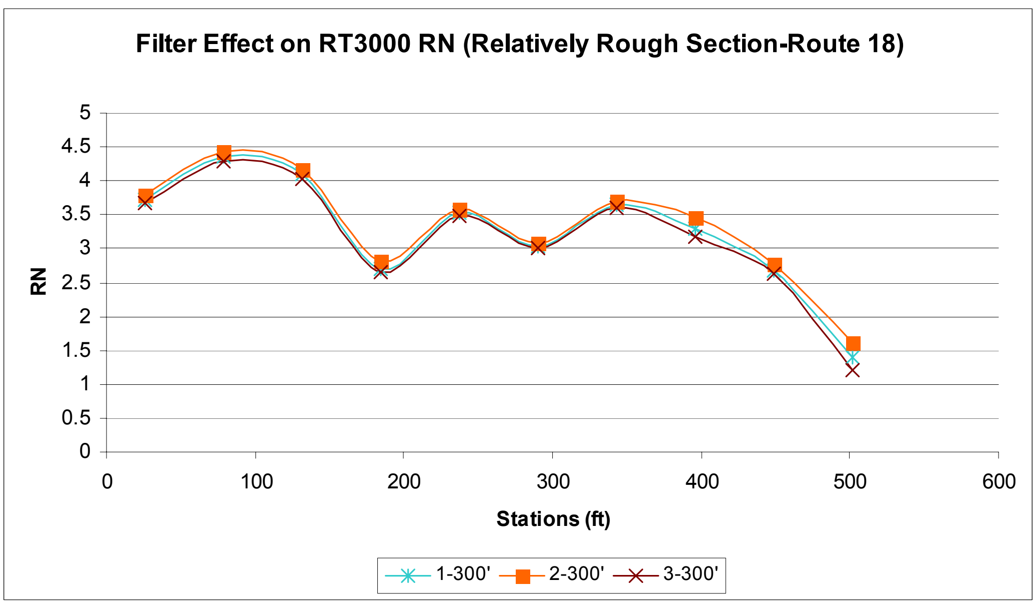


Figure 99c. Filter Effect on RT3000 - RN (Relatively Rough Section - Route 18).

Table 14. Maximum Difference in RN Unfiltered and Filtered Profiles for 52.8-ft Sub-section.

	Low Pass Filters (ft)			High Pass Filter (ft)			Band Filters-Cutoff Length (ft)		
SECTION 1 - Smooth, RN									
	1	**2**	**3**	**100**	**200**	**300**	**1-300**	**2-300**	**3-300**
R&L	0.05	0.86	1.15	0.11	0.08	0.05	0.05	0.86	1.14
WP	0.04	0.28	0.43	0.03	0.03	0.03	0.13	0.28	0.41
RT3000	0.07	0.18	0.28	0.14	1.94	0.01	0.78	0.74	0.28
SECTION 11 - Very Smooth, RN									
R&L	0.01	1.29	1.88	0.03	0.03	0.03	0.02	1.38	1.87
WP	0.00	0.63	0.9	0.06	0.06	0.06	0.02	0.63	0.84
RT3000	0.36	1.06	1.38	0.8	0.8	0.79	0.36	1.06	1.31
SECTION 23 - Relatively Rough, RN									
R&L	0.02	0.61	0.83	0.05	0.05	0.05	0.21	0.61	0.87
WP	0.01	0.57	0.37	0.02	0.01	0.02	0.41	0.57	0.91
RT3000	0.12	0.42	0.66	0	0	0.16	0.2	0.42	0

PI Sample Results

Table 15 shows the PI values for all the sections/devices considered in this study. As can be seen from this figure, there are distinct differences in the PI values of the three roughness classes. The PI values for the very smooth category are in the range of 0.69 to 3.26. The corresponding ranges for the smooth and relatively rough categories are 13.25 to 36.60 and 40.76 to 142.10, respectively. This suggests that PI limits can be established to classify pavement sections in the three roughness classes with no overlaps. These limits could not have been established using RN.

Table 15. PI for Different Roughness Classes (528-ft Sections).

	R & L	WP	ARAN-40	Dynatest-40	RT3000-40
Route 55 (very smooth)					
S11	1.63	2.05	3.26	2.43	2.26
S12	1.79	2.59	2.25	2.11	1.87
S13	1.74	1.48	0.97	2.88	0.69
Route 195 (smooth)					
S1	23.08	13.25	16.83	21.20	18.28
S3	19.54	13.88	23.75	36.60	24.05
S4	19.83	17.04	19.15	23.78	18.12
Route 18 (relatively rough)					
S23	49.42	50.32	76.98	88.05	40.76
S24	116.30	103.30	67.40	106.20	61.97
S25	97.84	97.84	47.34	142.10	75.13

RSE Sample Results

Table 16 shows the %DL values for all the sections/devices considered in this study. As can be seen from this table, there is significant variability among devices. Although there is a significant variability among devices, there is a clear difference among the roughness category for the same equipment, the smoother the section the lower the %DL.

Table 16. %DL for Different Roughness Classes (528-ft Sections).

	R&L	WP	ARAN-40	Dynatest-40	RT3000-40
Route 55 (very smooth)					
S11	0.15	0.00	0.81	0	0.05
S12	0.44	0.00	0.00	0	0.00
S13	0.00	0.00	0.00	0.016	0.00
Route 195 (smooth)					
S1	4.64	2.24	2.57	3.88	4.67
S3	3.29	2.55	2.95	3.18	2.24
S4	2.69	2.10	2.44	0.79	2.24
Route 18 (relatively rough)					
S23	13.76	13.34	32.65	19.74	13.03
S24	34.55	34.34	42.67	31.09	31.06
S25	32.60	19.79	16.04	20.26	30.81

NEW RIDE STATISTICS

Road surface roughness is defined as the deviation of a pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, and dynamic loads. Roughness along a wheel track can be quantified by measuring the longitudinal profile, and recording the deviations of the pavement surface perpendicular to an established reference parallel to the lane direction. Rideability, on the other hand, is a subjective judgment of the comparative discomfort induced by traveling over a specific section of highway pavement in a vehicle (ASTM E867, 2002). Ride quality, the user perception of rideability, is a subjective measure while road roughness, measured as a longitudinal profile along each wheel track, is an objective measure. To obtain the relationship between the two measures, the longitudinal profile measurement data should first be reduced to a representative ride statistic. Then, a controlled panel study should be conducted to relate the subjective panel ratings to the calculated ride statistics in the form of regression equations. Depending on the obtained correlations with mean panel ratings (MPR), the calculated ride statistics is modified to a rideability index (RI).

Ride statistics summarize the roughness information in the longitudinal profile measurements (profiles) as related to rideability. Measured profiles consist of a discrete set of elevation values taken at a constant interval along a wheel track by a profiler. A profiler is a general name for any instrument being used for this purpose. Profiler measurements of a road segment provide only an approximation of the “true profile” of the road. It is neither economical nor useful to obtain the true profile with enough detail to extract road texture information, as well as road geometry features, such as hills and valleys. (5) On the other hand, the profile measurements should be repeatable and contain all the roughness information of the true profile which influences ride quality. In other words, the obtained profile should yield the same ride statistics as the true profile. To find a standard profiler for NJDOT, the repeatability and accuracy of a number of common profilers were investigated in this study, and the results and recommendations were included in the foregoing sections of this report. In this part, it is assumed that the profile is a sufficiently accurate estimate of the true profile.

Ride Statistics

A number of different ride statistics commonly used for ride quality assessment are presented in this section. Some of the ride statistics which are being used to quantify the road roughness are:

- Percentage Defective Length (% DL)
- Ride Quality Index (RQI)
- Root Mean Square (RMS) Vertical Acceleration (RMSVA)
- Mean Absolute Vertical Acceleration (MAVA)
- Slope Variances (SV)
- Power Spectral Density (PSD) distribution
- International Roughness Index (IRI)
- Half-Car Roughness Index (HRI)
- Ride Number (RN)

Among these, the International Roughness Index (IRI), a common index adopted by a number of state DOTs and other public agencies, is discussed in more detail. Some of the shortcomings of using IRI for assessing the rideability of a road segment are pointed out. Important factors to be considered in developing a rideability index are pointed out, also. Finally, the proposed ride statistics, Total Intensity (TI), is introduced and its calculation and implementation for ride quality assessment is discussed in detail. Brief descriptions of the above indices are provided in the following sections.

Percentage Defective Length (% DL)

Profilographs and RSEs measure the vertical deviations of the pavement surface from a moving reference plane of a fixed length. The measured deviations are then compared to a maximum allowable tolerance (usually about 1/8 inch). The segments with deviations exceeding the allowable tolerance are identified as defective. The ratio of the total length of defective segments to the accumulative length of all tested segments is reported as Percent % DL.

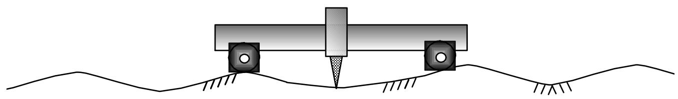


Figure 100. RSE and Measurement of %DL.

Ride Quality Index (RQI)

The RQI measures the level of road roughness felt by passengers traveling in cars.[18] A road profile normally constitutes various features covering a wide range of wavelengths. The distribution of the energy of the profile among different wavelengths is estimated by PSD functions. In the late 1960's, the Michigan DOT conducted a series of psychological experiments to relate the user opinion of the quality of the road to certain wavelengths in profile PSD distributions. Based on the results of this experiment, an electronic filter was later developed by Michigan DOT to calculate a profile–based statistic called the RQI. RQI has been revised several times since then, and the details of its current implementation are not yet published.[15]

RMS Vertical Acceleration (RMSVA)

$RMSVA$ is a profile-based statistic which is defined as the RMS value of the second derivative of profile (z) with respect to the distance or vertical acceleration. Let $z_1, z_2, \ldots$ and z_n represent elevations of equally spaced points along one wheel path of the profile (Figure 101). If Δ is the sampling interval, then a simple estimate of the second derivative of profile (z) at any point i or with respect to the distance is:

$$VA = \left(\frac{1}{k\Delta}\right)\left(\frac{z_{i+k} - z_i}{k\Delta} - \frac{z_i - z_{i-k}}{k\Delta}\right) = \left(\frac{z_{i+k} - 2z_i + z_{i-k}}{(k\Delta)^2}\right) \quad (1)$$

where k is an arbitrary integer and VA is the second derivative or the vertical acceleration of the profile with respect to the base length, $b = k\Delta$. Root mean square vertical acceleration ($RMSVA$) corresponding to the base length, b, can be expressed as:

$$RMSVA_b = c\sqrt{\sum_{i=k+1}^{i=n-k} VA^2 /(n-2k)} \quad (2)$$

where c is a constant required for unit conversion from a spatial acceleration to a frequency domain acceleration and n is the total number of elevation points. The $RMSVA$ statistics can be computed for any base length, b. Varying the bandwidth allows the inclusion of various roughness features into the statistics. [12]

$RMSVA$ calculated with two different base lengths of 4 ft, $RMSVA_4$, and 16 ft, $RMSVA_{16}$ were combined to develop a new ride statistics called MO. The symbol MO refers to a reference Mayes ride meter.(12)

$$MO = -20 + 23RMSVA_4 + 58RMSVA_{16} \quad (3)$$

The regression coefficients are valid when the MO statistics is in the units of inches per mile and $RMSVA$ values are in feet per second squared.(12) Research has shown that MO correlates highly with IRI(5), which will be discussed later in this section.

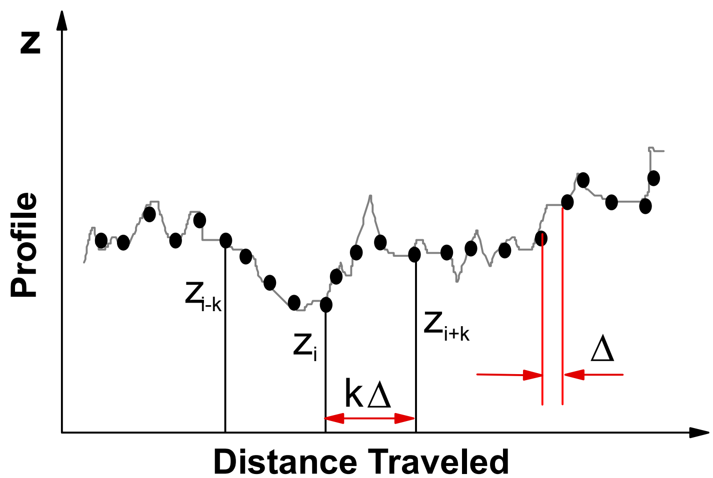


Figure 101. Calculation of RMSVA, MAVA and SV.

Mean Absolute Vertical Acceleration (MAVA)

$MAVA$ is a profile-based statistics which is calculated as the mean value of the second derivative of profile (z), vertical acceleration, at any point i or with respect to the distance:(13)

$$MAVA_b = \sum_{i=k+1}^{i=n-k} |VA| / (n-2k) \quad (4)$$

All the parameters in this equation have been defined previously for equations 1 and 2 and some of them were illustrated in Figure 101.

Slope Variance (SV)

The Slope Variance (SV) is another profile-based ride statistics developed to characterize road roughness. SV is defined as the statistical variance of the profile slope (calculated over 1 ft intervals) by the following equation:

$$SV = \frac{\sum_{i=1}^{n} (S_i - \bar{S})^2}{n-1} \quad (5)$$

where S_i is surface slope in radians at point i, $\bar{S}$ is the mean slope in radians and n is the total number of slope data.(13)

PSD Distribution

The frequency content and amplitude of vehicle-induced vibrations are the most important factors in determining the quality of ride as experienced by passengers. The sensitivity of the human body to the frequency content of the imposed vibrations in different directions is provided as frequency weightings in the International Standard ISO 2631-1. The frequency weightings applicable to the vertical vehicular excitations are presented in Figure 102. It can be observed that, for the vertical vibration, the weighting has the greatest sensitivity in the range of 4 to 13 Hz.(19) On the other hand, the results of some recent studies suggest that the vertical vibrations at low frequencies (0.1 t0 0.5 Hz) may cause motion sickness.(20) Frequency characteristics of the vehicle vibrations are directly related to the frequency spectrum of the road profile through the transfer function of the vehicle. Power spectral density analysis relies on the frequency content of the road profile to assess rideability.

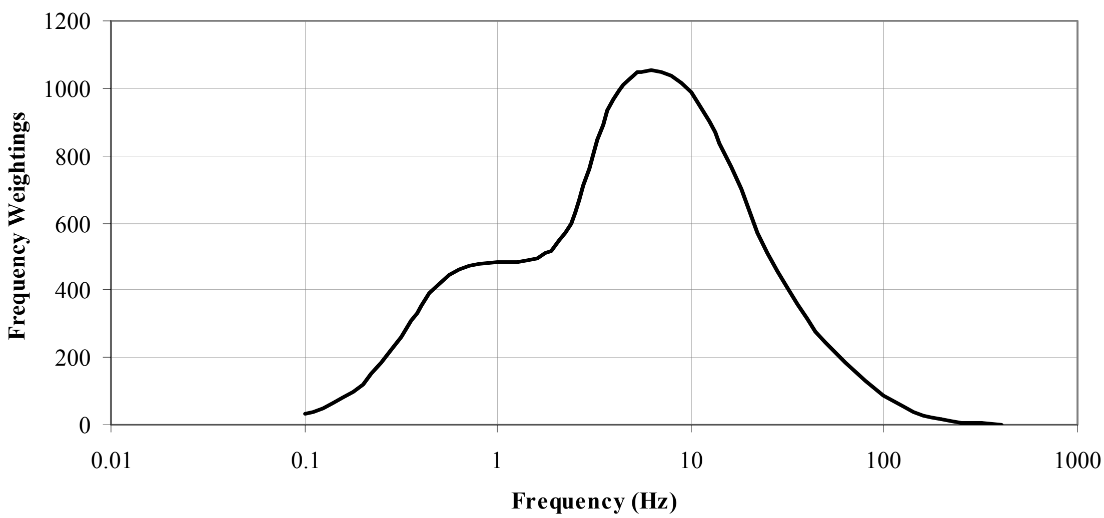


Figure 102. Frequency Weightings for Vertical Vibrations (from ISO 2631-1:1997).

A longitudinal pavement profile constitutes various features of different wavelengths ranging from a pulse like disturbances of a short wavelength, to long wavelengths of the road geometrical curve. Any profile can be thought of as a linear combination (sum) of sinusoids of different frequencies (wavelengths), amplitudes and phase angles. For example, an arbitrary $N-$point profile z can be represented by a Fourier series as:

$$\begin{aligned} z(n) &= A_0 + A_1\cos(2\pi f n\Delta + \varphi_1) + A_2\cos(2\pi(2f)n\Delta + \varphi_2) + \ldots \\ &+ A_k\cos(2\pi(kf)n\Delta + \varphi_k) + \ldots \end{aligned} \tag{6}$$

where $z(n)$ is the profile elevation of the n the point, f is the fundamental frequency of the profile (reciprocal of the total length of the profile), k is an arbitrary integer, Δ is the sampling interval, A_k and φ_k are the amplitude and phase angle at frequency kf. The series could also be written in the following equivalent form:

$$A_k \cos(2\pi(kf)n\Delta + \varphi_k) = a_k \cos(2\pi(kf)n\Delta) + b_k \sin(2\pi(kf)n\Delta)$$

$$\begin{aligned} a_k &= A_k \cos(\varphi_k), \\ b_k &= -A_k \sin(\varphi_k), \\ a_k^2 + b_k^2 &= A_k^2 \end{aligned} \qquad (7)$$

Fourier transform is commonly employed to calculate the amplitude and phase angle of each frequency component. Coefficients a_k and b_k are, to within constants, the real and imaginary parts of the Fourier transform. Relating the above series to usual frequency characteristics gives:(14)

Mean square at frequency $kf = A_k^2$ (8)

PSD estimate at frequency $kf = A_k^2 / 2f$ (9)

Plotting PSD amplitudes of the profile versus frequency or wavelength provides an estimate of distribution of the energy of the profile among various wavebands. PSD estimation can be computed for elevation, profile slope, or acceleration.

PSD analysis has been used to find out what wavelength range contributes most to the road roughness in several research experiments.(14,21,22) Commonly, RMS values are calculated for profile (or slope) PSD amplitudes over various third octave frequency bands. These RMS amplitudes are then correlated to the corresponding MPR obtained from a controlled panel study. Therefore, a range of frequencies giving the best correlation with MPR can be identified which usually lies above the most sensitive range of human response to vibration.(14)

PSD analysis is also one of the best commonly used diagnostic tools for interpreting pavement properties. PSD estimation of the profile gives much more information about the profile than any other ride index. PSD analysis determines how the energy of the profile is distributed among its different frequency components. By examining the PSD function, one can determine whether short or long wavelengths are dominating throughout the profile. Therefore, it can help identify features in profiles that contribute to roughness. For example, roads with an energy concentration over short wavelengths are more likely to have cracks, patches, slab faulting and other forms of short-lived surface disturbances contributing to roughness.

IRI and HRI

The IRI is a ride statistic defined based on the results obtained from the simulation of a simple car model known as a quarter-car. The HRI is similar to IRI, but is defined based on the simulation of a half-car model. Before introducing the definition of IRI, the principles of quarter-car simulation are discussed. A brief overview of the process of developing IRI and its definition is presented next. The concept of IRI and its applicability as a ride quality index are further discussed. The IRI filter is introduced and the effects of the speed of simulation and parameters of the quarter-car on the IRI filter are illustrated. A number of issues regarding the choice of base length in calculating IRI are also pointed out. Finally, the definition of HRI and its similarity to IRI is provided.

Quarter-Car and Golden Car

Quarter-car is a simplified 2-DOF (Degree of Freedom) model of a passenger car used to simulate vibrations of the body and axle of the car while driving. A quarter-car model constitutes of a single wheel and its attached suspension system (Figure 103). The wheel is modeled as a linear vertical (to the road profile) spring of stiffness k_t. The inertial effects of the body and axle of the car are considered by two lump masses: sprung mass m_s and unsprung mass m_u which include a quarter of the mass of the body of the car and half of the mass of the axle, respectively. The suspension system is modeled as a combination of a linear spring of stiffness k_s and a viscous damper of coefficient c_s .

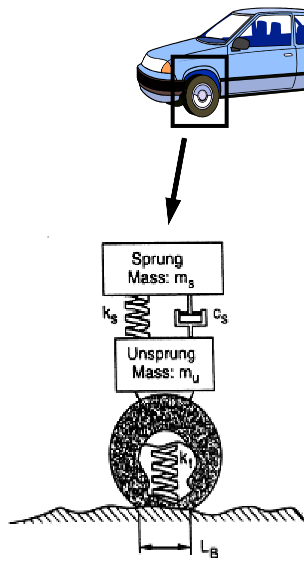


Figure 103. Quarter-Car Model and its Corresponding Parameters (from Sayers, M. W.[15]).

The concept of the Golden Car was developed in the late 1970's during a NCHRP sponsored study of response-type road roughness measuring (RTRRM) systems.[15,24] The objective of this study was to develop calibration and correlation procedures for RTRRM systems commonly used at the time, such as the Bureau of Public Roads (BPR) Roughometer, Mays- and PCA-type road meters. Analysis of the output of the RTRRM systems participating in the study indicted that those measure different characteristics of road roughness. The correlation among different systems is, therefore, a measure of the correlation between different road roughness spectral characteristics. It was also concluded that, because of high degree of nonlinearity in the systems, calibration can only be accomplished by means of a full spectrum excitation as experienced on a road. [24] The researchers concluded that the only valid calibration method for the response-type systems was calibration by correlation against a standard roughness index.[15] Average rectified velocity (ARV) of the axle-body vibration obtained from a quarter-car simulation was chosen as the candidate roughness index.[24] To choose the reference index, the quarter-car simulation was carried out with 10 alternative sets of parameters. The best correlation among RTRRM systems was obtained against the index calculated by using a quarter-car simulation with a particular set of parameter values that is often referred to as the Golden car parameters.[15] Results obtained from the systems participating in the correlation program showed that RTRRM systems were capable of measuring road roughness on the reference ARV (RARV) scale with a nominal accuracy of 10% after primary calibration.[24] The Golden Car parameters are such that:[15]

$$c = \frac{c_s}{m_s} = 6.0$$

$$k_1 = \frac{k_t}{m_s} = 653$$

$$k_2 = \frac{k_s}{m_s} = 63.3 \qquad (10)$$

$$\mu = \frac{m_u}{m_s} = 0.15$$

It should be noted that, despite what many researchers and users assume, the Golden Car parameters do not describe an average American passenger car, circa 1978. Spring rates were selected to match the two major resonant frequencies (body and axle bounce), but damping in the Golden Car is much higher than in most cars and trucks. The higher damping was chosen because it improved correlation with a wide variety of RTRRM systems.

IRI

IRI was developed during International Road Roughness Experiment (IRRE), a correlation experiment initiated by World Bank in 1982.[15,25] The objective of the experiment was to establish correlation and calibration standards for road roughness measurements all over the world. The study concluded that all roughness-measuring instruments in use at the time could produce comparable measurements on the same scale, if that scale had been selected suitably. Many roughness indices applied to the large amount of test data obtained in the IRRE. The best correlations between a roughness index and the response-type systems were found with the profile index obtained from the Golden Car simulation (with a defined forwarding speed) in the NCHRP research project.

The IRI is defined as an accumulation of the simulated motion between the sprung and unsprung masses in the quarter-car model with Golden Car parameters, normalized by the traveled length L, of the profile:[15]

$$IRI = \frac{1}{L} \int_0^{L/V} \left| \dot{y}_s - \dot{y}_u \right| dt \qquad (11)$$

where V is the velocity of the quarter-car, y_s and y_u are the vertical coordinates of sprung and unsprung masses, t is time and the dots (in $\dot{y}_s$ and $\dot{y}_u$) indicate time derivatives. The value of IRI is expressed in the units of m/km (or inch/mile). In the definition of IRI, V is defined as 49.7 mph.

IRI as a Ride Quality Index

As discussed in the previous sections, IRI was developed as a calibration reference index, not as a ride quality index. Two main factors were considered in developing the IRI. First, it had to be measured with a wide range of equipment, including RTRRM systems. Second, it had to be defined as a mathematical transform of a measured profile. Among many different indices applied to the large amount of test data collected in the IRRE, the reference ARV (RARV) index developed in the NCHRP project provided the best correlations for various RTRRM systems. It was also concluded that the measurement of RARV with properly calibrated RTRRM systems was related to pavement serviceability. The RARV was defined based on the simulation of a quarter-car model with Golden Car parameters. To make the new index relevant to ride quality, the speed of the simulated Golden Car used in definition of the index was set to 49.7 mph, because at that speed, the IRI is sensitive to the range of frequencies that cause vehicle vibrations while driving on highways.[15,24]

The IRI is defined as the average rectified absolute velocity between the body and axle of the Golden Car simulated at the speed of 49.7 mph. The definition of IRI evolved from the calibration and correlation studies to find a common reference index for road roughness measuring equipments, including RTRRM systems. In defining the IRI, correlations with the user opinion of the quality of the ride through subjective panel ratings were not established.

Conceptually, the accumulated relative motion between the body and axle of the car is a measure of the work done by the shock absorbers (damper) of the car. The work done by the damper in the quarter-car model (Figure 104) can be described as:

$$W_{F_c} = \int F_c dy = \int c_s (\dot{y}_s - \dot{y}_u) v(t) dt = \int_0^{L/V} c_s (\dot{y}_s - \dot{y}_u)^2 dt \qquad (12)$$

where W_{F_c} is the work done by the damper force F_c and $v(t)$ is the relative velocity between the body and axle of the car. The other parameters are the same as those defined for equation 11. Comparing equations 11 and 12, it can be observed that the RMS of W_{F_c}, scaled by a constant ($\frac{1}{c_s L}$) would be very similar to the definition of IRI. The RMS value of the relative motion between the body and axle of the car (sprung and unsprung masses in the definition of IRI), was indeed one of the candidate reference indices while developing the IRI but, was not selected as the reference index. RMS averaging was found less convenient because it is nonlinear with respect to the relative motion, whereas equation 11 is linear. Another reason for using linear averaging was to match the behavior of existing road meters.[15]

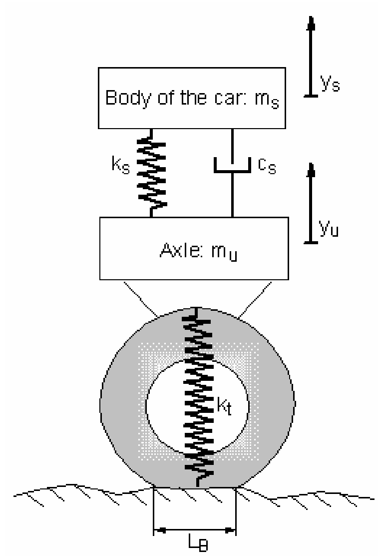


Figure 104. Quarter-Car Model Parameters.

While the IRI measures the work done by the shock absorbers of the car, the quality of the ride is determined by the level of vibrations of the body of the car as experienced by passengers. The ultimate case can be considered when the body of the car travels along a straight line, while the relative movement between the body and axle absorbs all of the vibrations induced by road roughness. This case is schematically depicted in Figure 105. In similar situations, the shock absorber is going through cycles of expansion and contraction, which if accumulated (absolute values) as in the definition of the IRI, can result in a large value. However, the body of the car is traveling along a much smoother path (a straight line in the illustrated ultimate case) and consequently, the level of vibrations experienced by the car passengers will be minimal resulting in their perception of having a smooth ride.

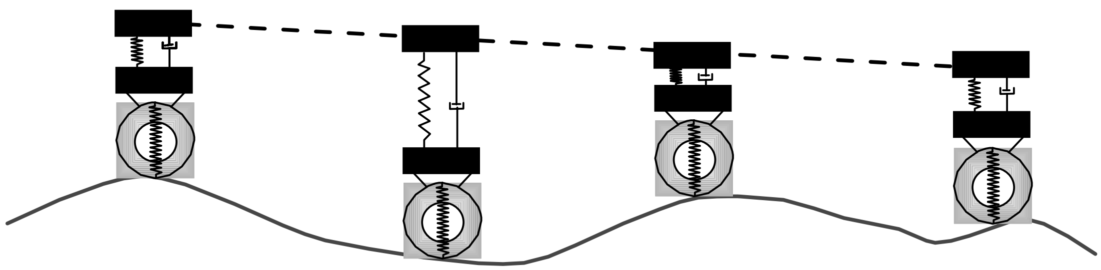


Figure 105. The body of the car (sprung mass) is traveling along a straight line while the shock absorbors (damper) is contarding and expanding.

To better illustrate the difference between the vibrations of the body of the car and the relative motion between the body and axle, two synthetic sinusoidal "profiles" with wavelengths of 10 ft and 100 ft and unit amplitude are considered. The profile, the vibration of the body of the Golden Car and the relative body-axle motion at the speed of 49.7 mph for these two synthetic profiles are presented in Figures 106 and 107.

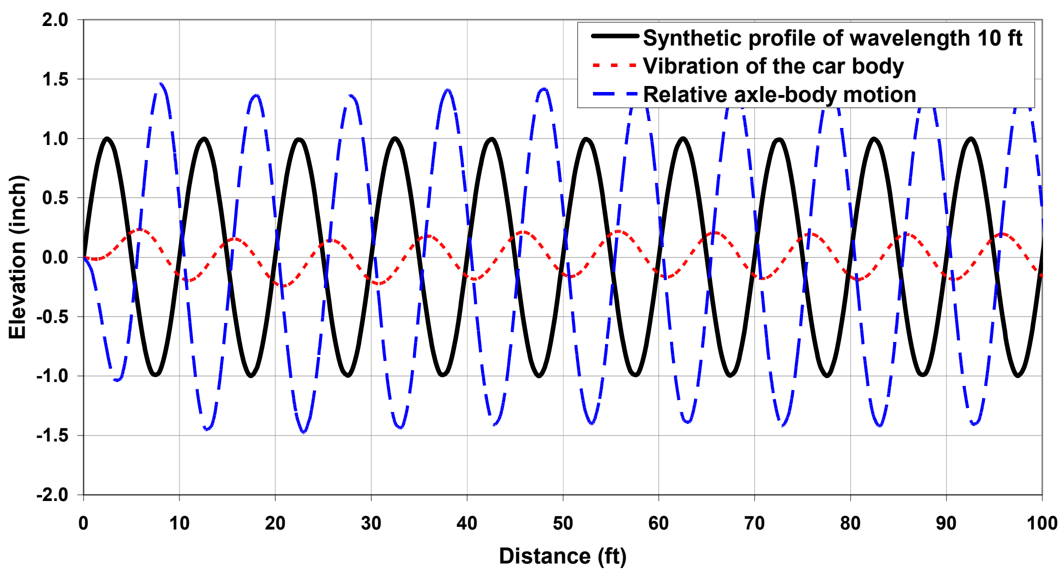


Figure 106. A comparsion between the vibrations of the body of the Golden Car and the relative axle-body motions.

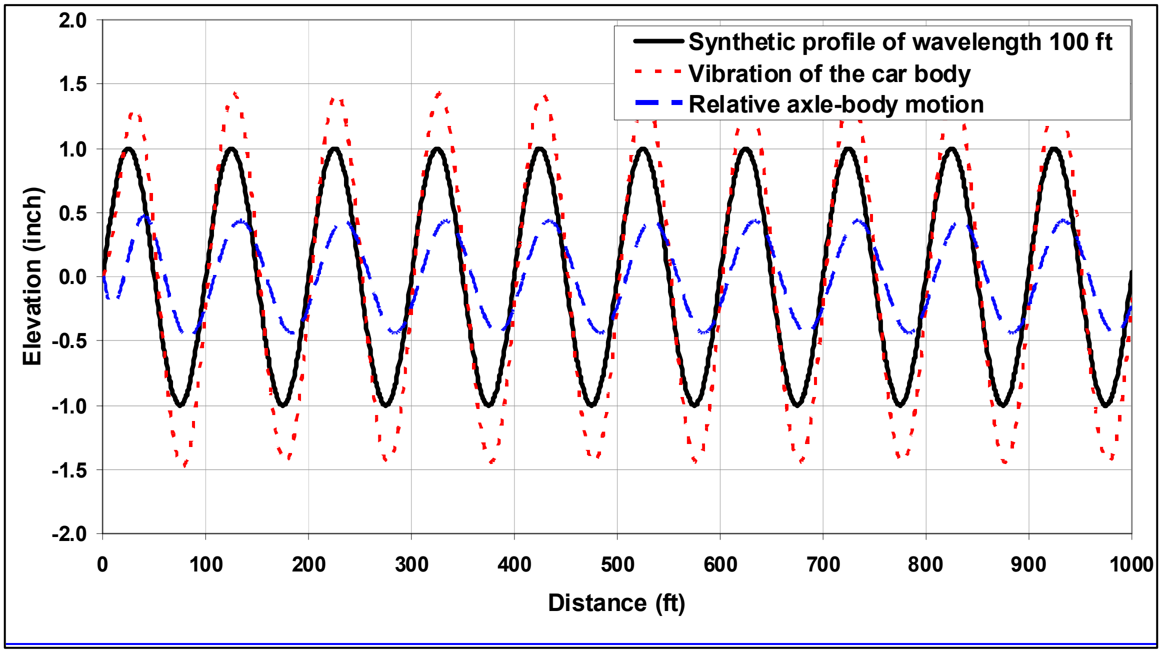


Figure 107. A comparsion between the vibrations of the body of the Golden Car and the relative axle-body motions.

As shown in Figure 108, repeated waves of wavelengths of 10 ft result in an amplified relative axle-body motion. However, the amplitude of the Golden Car body will be only a fraction of the input roughness. On the other hand, repeated waves of wavelength 100 ft will produce amplified vibrations in the body of the car. The amplitude of the relative axle-body motion will be about half of the amplitude of the input synthetic profile. It can be clearly observed that different road roughness features of different frequencies affect the vibrations of the body of the car (important in subjective ride quality assessment) and the relative axle-body vibrations (used in the definition of IRI) in very different ways.

IRI Filter

The IRI can be related to a filter called the IRI filter, whose input is the profile and its output the relative motion between the body and axle of the Golden Car (unsprung and sprung masses). Referring to the parameters defined in equations 11 and 12, the IRI filtering operation is described schematically in Figure 108. The output of the IRI filter, the filtered profile, if accumulated (absolute values) and normalized by the length of the profile L, gives the IRI value of the input profile. The IRI filter and the filter corresponding to the vibrations of the body of the car are shown in Figure 109. If this filter is applied to a profile, the output will be the vibration of the body of the car. It can be seen that the two filters have similarities and differences. The IRI filter has two peaks at about the resonant frequencies of the Golden Car dynamic model, 1.2 (60.3 ft) 11 Hz (6.6 ft). The body of the car filter has also two peaks but compared to the peaks of the IRI filter, they are shifted towards lower frequencies (larger wavelengths). Furthermore, while the higher frequency (smaller wavelength) peak can be hardly distinguished, the lower frequency (larger wavelength) one is very pronounced. The filters represent very different absolute gains for the same range of wavelengths (frequencies). It is obvious that different frequency components of the profile will be affected very differently by these two filters. Therefore, in general, the output of theses two filters will be very different.

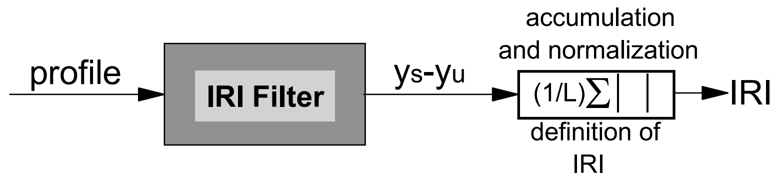


Figure 108. IRI Filter.

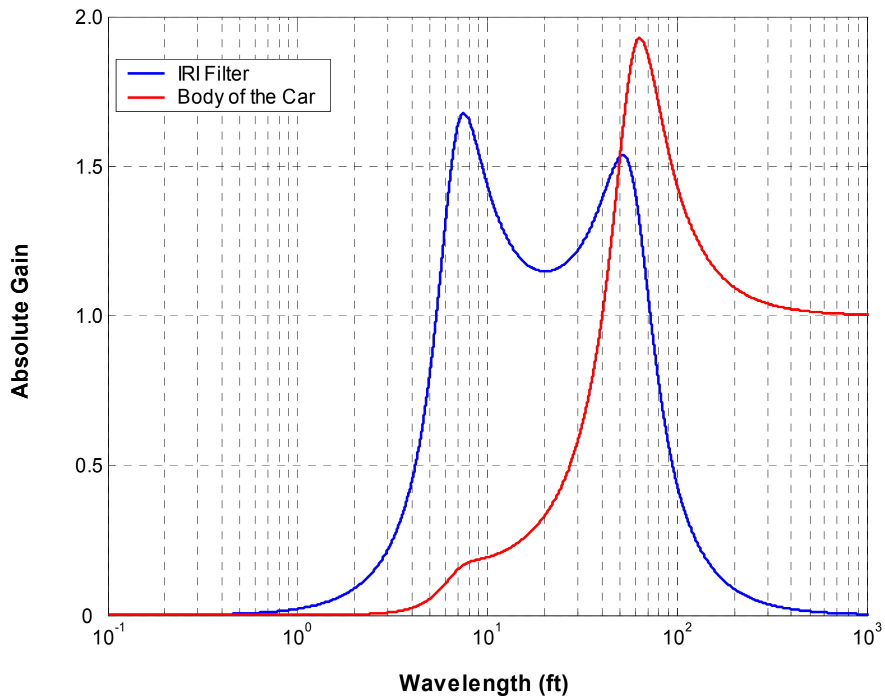


Figure 109. IRI and Body of the Golden Car Filters.

It is important to find out what wavelength (frequency) range actually contributes to the road roughness. It is obvious that very small wavelengths do not contribute to road roughness because the vehicle tires are too wide for these wavelengths to cause any vibration.(11) This enveloping behavior of pneumatic tires on highway vehicles has been accounted for in the IRI calculation. Before applying the IRI filter, the profile is smoothed by a moving average filter of base length (L_B) of 9.8 inch.(15) Similarly, very large wavelengths of the road geometry (vertical curves) are not affecting the vehicle vibrations at all. There is a certain wavelength range which affects the vehicular vibrations and therefore contributes to road roughness. This range lies in between 0.3 to 328 ft, but no further information is available.(11) The narrower range of wavelengths that contribute most to road roughness and affect ride quality can be determined by carrying out controlled subjective panel ratings. These should be accompanied by profile measurements using different measuring systems and establishing correlations between the MPR and different wavelength ranges in the obtained profiles. For a ride statistic to be a good representative of ride quality, it should be sensitive to the range of wavelengths (frequencies), which contribute the most to road roughness and affect the quality of ride. In other words, the band pass range of the filter corresponding to the ride statistics should cover the range of wavelengths (frequencies) affecting ride quality, and shape of the filter (the distribution of filter the gain among various wavelength bands) should be compatible with the sensitivity of the level of ride comfort to different wave bands.

There is no definite conclusion about the range of wavelengths (frequencies) that affect ride quality. As can be seen in Figure 109, the band pass range of the IRI filter is from 1 to 13 Hz (5.6 to 72.9 ft). This frequency range is about the range of the greatest sensitivity of sitting human beings to the vertical vibrations (4 to 13 Hz), which is shown in Figure 102.(19) Wambold reports that car passengers are most sensitive to frequencies between 5 and 15 Hz .(26) Janoff, on the other hand, concludes that the ride quality is associated to a higher frequency range of 8 to 50 Hz.(27) To explain this discrepancy, Hayhoe performed an extensive correlation study involving 162 pavement profiles. The frequency range was divided into a number of successive third octave bands and the logarithm of RMS profile elevation in each third octave band was correlated against available MPR for various combinations of data sets and pavement types. This resulted in identification of a frequency band giving the best correlation with MPR, which lies above the most sensitive range of human response to vibrations. It is argued that the presence of large amplitude pulses (short-lived disturbances) has a significant effect on ride quality. This effect cannot be accurately predicted using human subjective response characteristics measured for sinusoidal vibration or wide-band random excitation.(14)

Effect of Velocity on IRI

In defining the IRI, the simulation speed of the Golden Car was fixed to 49.7 mph. It was argued that at that simulated speed, the IRI is sensitive to the same profile wavelengths that cause vehicle vibrations in normal highway use.(15) The speed limit ranges from 25 mph in residential areas to 65 mph on major NJ interstate highways. The traveling speed of a vehicle has significant effects on the vibrations perceived by the passengers and, therefore, is an important factor in rating the quality of the ride. Not considering the effect of vehicular speed may be justified for a calibration reference index, but may not be ignored for developing a ride quality index. To illustrate the effect of vehicular speed on the range of wavelengths contributing to road roughness and affecting ride quality, the frequency range suggested by International Standard ISO 2631-1 as the range to which sitting humans are most sensitive, 4 to 13 Hz, is translated into wavelength range at different speed levels and presented in Table 17. It can be observed that the same frequency range results in non-overlapping wavelength ranges for vehicle speeds of 30 and 75 mph.

Table 17. Effect of Speed on the Range of Wavelength Corresponding to the Frequency Range of 4 to 13 Hz.

Speed (mi/h)	Range of Wavelength (ft)	
30	5.50	11.01
40	7.34	14.68
50	9.17	18.35
65	11.93	23.85
75	13.76	27.52

The effect of the speed of simulations on the RI filter is presented in Figure 110. As expected, increasing the speed shifts the filter toward lower frequencies (larger wavelengths). Passengers in a car traveling at higher speeds do not "feel" the same type of shorter wavelength features of the profile as those traveling at lower speeds.

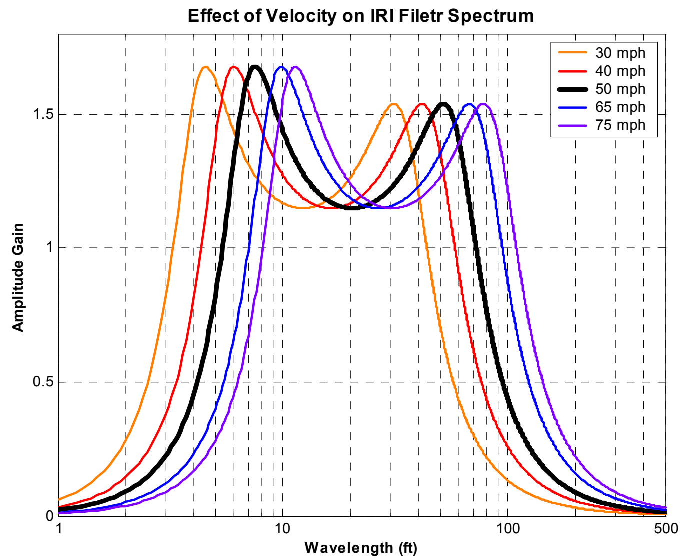


Figure 110. Effect of Vehicular Speed on IRI Filter.

Since varying the simulation speed shifts the IRI filters, it will change the resulting IRI values as well. The IRI values obtained from the Golden Car simulation at various speeds for a number of profiles collected in this study (rod and level) are presented in Figure 111(a). Generally, a lower simulation speed results in a higher IRI value ("rougher" profile), and vice versa. The deviation of calculated IRI values from the one obtained based on the standard definition (simulation speed of 49.7 mph) is calculated as IRI Difference (equation 13) and illustrated in Figure 111(b). As it is shown in Figure 111(b), varying the simulation speed can change the value of IRI by 35%.

$$IRI\ Difference_{for\ simulation\ speed\ V}\ (\%) = \frac{IRI\ (simulation\,speed = V) - IRI\,(simulation\,speed = 50mph)}{IRI(simualtion\,speed = 50mph)} \qquad (13)$$

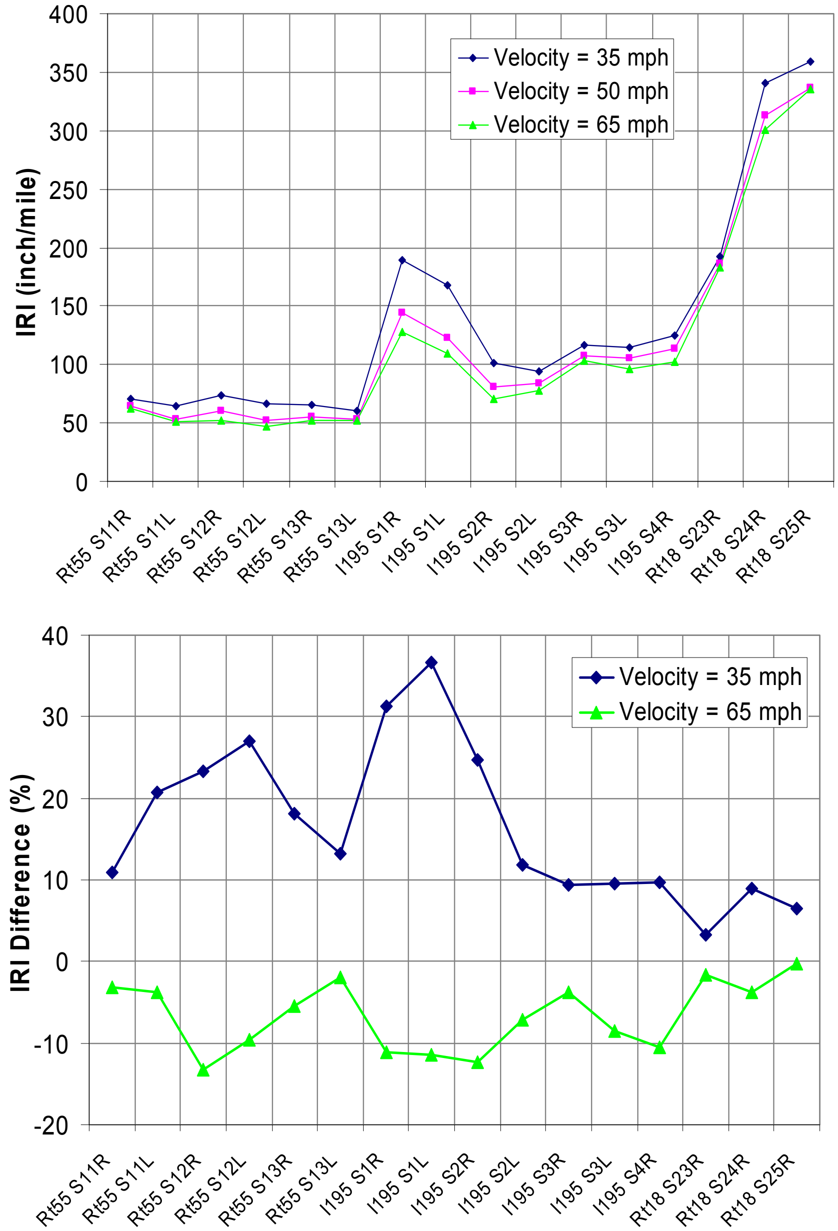


Figure 111 (a) and (b): Effect of Vehicular Speed on IRI Values.

(Note: To be precise, the index calculated by varying the simulation speed cannot be called IRI. In the definition of IRI, the simulation speed of the quarter-car is set to 50 mph. The term IRI has been used here to indicate that except for the simulation speed, the index is calculated in exactly the same way as IRI).

Effect of Quarter-Car Parameters on IRI filter

Golden Car parameters were selected in the definition of IRI because they resulted in the best correlations between a profile index and the response-type road roughness measuring systems. However, these parameters do not describe an average passenger car.[15] Varying each of the parameters may significantly alter the shape of the IRI filter. For example, the quarter-car parameter μ (defined in equation 10) is recalculated based on the parameters of the vehicle dynamics model used for simulations at the Ford motor company (Table 18 and equation 14).[28] For a Golden Car, the value of μ is set to 0.15. The changes in the IRI filter due to varying the parameter μ between 0.05 to 0.15 is illustrated in Figure 112. Decreasing the value of μ from 0.15 to 0.05, results in a slightly wider and significantly shorter higher frequency (shorter wavelength) peak, which is coming from the vibration of the axle of the car.

Table 18. Some Basic Vehicle Parametrs (from Kao and Artz).

Body mass, m_B (Kg)	1011.31	Driver and passengers, m_P (Kg)	147
Engine, m_E (Kg)	304.4	Front unsprung mass, m_{Fu} (Kg)	42.39
Subframe, m_{Sf} (Kg)	24.57	Rear unsprung mass, m_{Ru} (Kg)	31.24

$$\mu = \frac{m_u}{m_s} = \frac{Total\ unsprung\ mass}{Total\ sprung\ mass} = \frac{m_{Fu} + m_{Ru}}{m_B + m_E + m_{Sf} + m_P} = \frac{42.39 + 31.24}{1011.31 + 304.4 + 24.57 + 147} = 0.05 \quad (14)$$

IRI Base Length

The test sites used in developing the IRI all had a length of about 0.2 mi; however, 0.1-mi sites are common. Theoretically, IRI can be computed for any length of profile. However, when IRI is summarized for longer sections, the higher values are not as high as when it is summarized for short sections. Therefore, it is essential to specify a standard base length, especially when IRI is used to identify maximum roughness.[15]

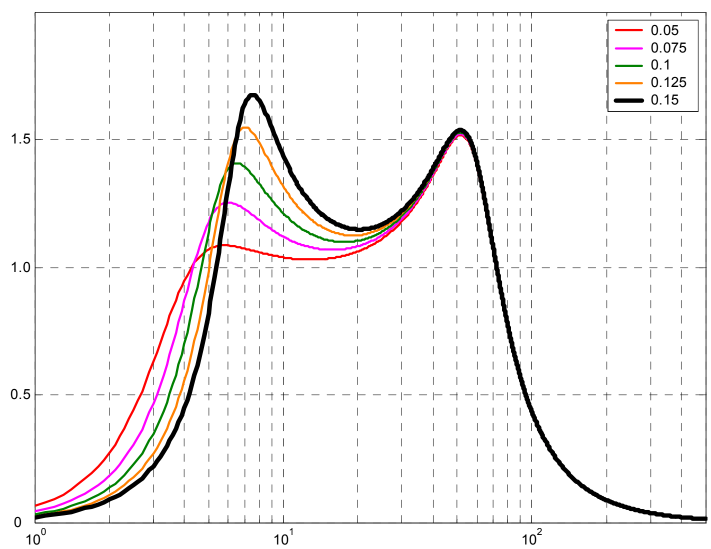


Figure 112. Effect of Varying the Parameter μ on the Shape of IRI Filter.

When choosing the base length for calculating the IRI, the effect of initialization in the IRI computational algorithm should be taken into account. To solve the differential equation governing the quarter-car dynamic system, one must know or estimate the initial values of the state variables. The response obtained over a length of profile is a superposition of a transient response coming from the given initial values and a steady-state profile-induced response. The effect of the initialization diminishes as the simulated car travels along the profile. At the IRI simulation speed of 80 km/hr, the initialization influences the quarter-car response for about 65.6 ft. The most accurate way to deal with the initialization effect is to measure the profile for 65.6 ft or so before the site and start the simulation there. Then, at the start of the test site, begin the IRI accumulation. [15] Because of initialization errors in the first 65.6 ft of the profile, the error in calculation of IRI over very short test sites is greater.

Half-Car Roughness Index (HRI)

The IRI is defined for a single wheeltrack profile. The half-car roughness index (HRI) is very similar to IRI, but it is defined for a pair of longitudinal profiles taken at two wheeltracks. The analysis is equivalent to the simulation of a half-car model, instead of the quarter-car model used in the definition of IRI (Figure 113). In the half-car model simulation, two input profiles corresponding to the left and right wheeltracks are allowed. It can be shown that the simplified model presented in Figure 113 is equivalent to a quarter-car model, using as input the point-by-point average of the left and right wheeltracks.[29] Therefore, both IRI and HRI can be obtained by simulation of a quarter-car model with Golden Car parameters. In the case of IRI, the input to the model is a single wheeltrack (left or right) profile, whereas for HRI, the input consists of the point-by-point average of profiles taken at two wheeltracks (left and right).

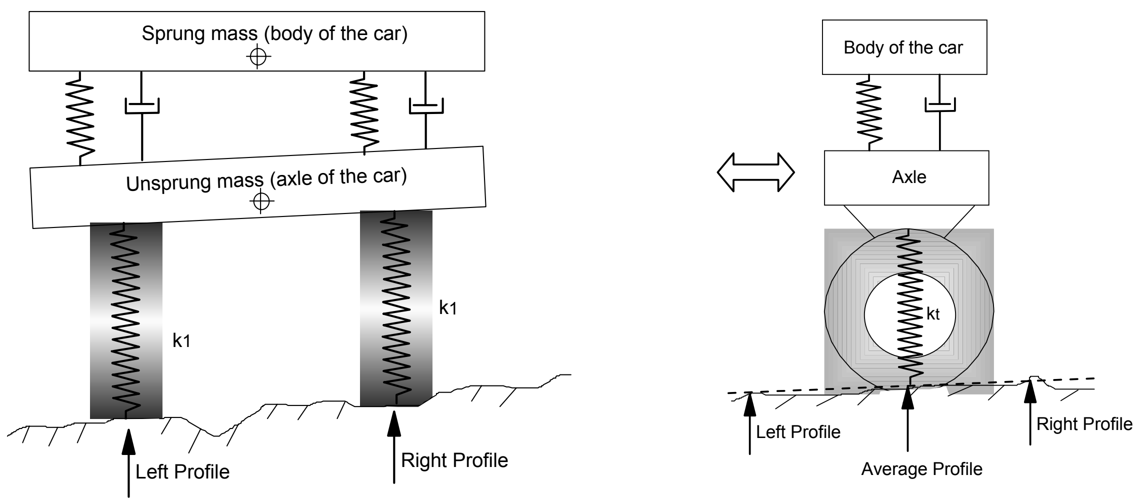


Figure 113. Half-Car Model and the Equivalent Quarter-Car Model.

Conceptually, the IRI is related to the vehicle response at the wheels, while the HRI is more related to the vehicle response at its center. However, the results obtained from the International Road Roughness Experiment (IRRE) indicate that the HRI is highly correlated to the average IRI value for left and right profiles (i.e. $(IRI_{left} + IRI_{right})/2$) for different types of pavements. For asphalt pavements:[29]

$$HRI \approx 0.8(\frac{IRI_{left} + IRI_{right}}{2}) \qquad (15)$$

This existing correlation suggests that the two indices can be interchangeable. Since some of the road roughness measuring systems (e.g. walking profiler) do not provide simultaneous measurements of profiles at both wheeltracks, the IRI may be considered a more general roughness index than HRI.

Ride Number (RN)

Ride number (RN) is a statistic developed to estimate pavement rideability from the measured longitudinal profile. RN was developed based on the correlations established between the mean panel ratings and spectral characteristics of profiled pavements for a large set of collected data from a number of studies.(22) RN is an exponential transform of another statistics called PI:(22)

$$RN = 5e^{-160(PI)} \tag{16}$$

PI is obtained from simulation of a quarter-car model with a different set of parameters than Golden Car parameters. The quarter-car parameters used in definition of PI are:(22)

$$\begin{aligned} c &= \frac{c_s}{m_s} = 17.0 \\ k_1 &= \frac{k_t}{m_s} = 5120 \\ k_2 &= \frac{k_s}{m_s} = 390 \\ \mu &= \frac{m_u}{m_s} = 0.036 \end{aligned} \tag{17}$$

The initialization length used to specify the initial values of state variables is changed from 36.1 ft (IRI) to 62.3 ft (PI). Also, for calculating PI, the accumulation is done by RMS, rather than mean absolute (IRI). If the profiles from both wheeltracks are available, RN is calculated based on an average value of PI calculated as follows:(22)

$$PI = \sqrt{\frac{PI_{Left}^2 + PI_{Right}^2}{2}} \tag{18}$$

The design of passenger cars in terms of vibration isolation has been significantly improved since the time of the conducted panel ratings, which were used to develop RN. On the other hand, the mechanism of the road roughness measuring systems have been changed and modified. Considering the above factors, it is very unlikely to obtain the same level of correlations for RN calculated from the profiles obtained using modern high-speed profilers and subjective ratings using modern vehicles. Therefore, RN may not provide a good estimation of human perception of rideability, if applied to new sets of profile data.

Mean Absolute Acceleration (MAA)

Considering the shortcomings of the IRI, alternative measures of ride quality can be introduced. Such measures should be based on the motion parameters that are more closely related to the motion experienced by a car occupant. In the case of the quarter car model, such a measure could be based on the motion of the body of the car, instead of the motion of the suspension system (relative motion of the car axle and body). In addition, since the source of the car vibrations is the pavement roughness, it is reasonable to describe it by some kind of a vibration potential function. As an example, a new measure of ride comfort and pavement smoothness named Mean Absolute Acceleration (MAA) is introduced.

MAA is the mean absolute acceleration of a motion of a body. In a physical sense, it can be viewed as an absolute work of the inertia force of a moving mass, and is defined as:

$$MAA = \frac{1}{L}\int_0^L |m\ddot{y}|\,dx \tag{19}$$

where m is the mass, L is the length of the profile, y is the vertical displacement and $\ddot{y}$ and represent vertical acceleration (second derivative with respect to time). MAA can be defined as an absolute or relative measure of the pavement roughness. The absolute MAA (AMAA) represents the mean absolute acceleration of a mass following perfectly the pavement surface, as illustrated in Figure 114. The acceleration is approximately equal to the product of the pavement surface curvature and the horizontal velocity of the movement of the mass. If the velocity is taken as a constant, AMAA can be defined based on the pavement curvature

$$AMAA = \frac{m}{L}\int_0^L c^2 |y''|\,dx = \frac{mc^2}{L}\int_0^L |y''|\,dx \tag{20}$$

where c is the velocity of the moving mass, y is the pavement vertical coordinate and y'' represents the pavement vertical curvature (second derivative with respect to distance). Considering the fact that acceleration (curvature) of the pavement of a certain wavelength is inversely proportional to the square of the wavelength, for all practical purposes, there is no need to eliminate the vertical geometry of the pavement from the measured profile.

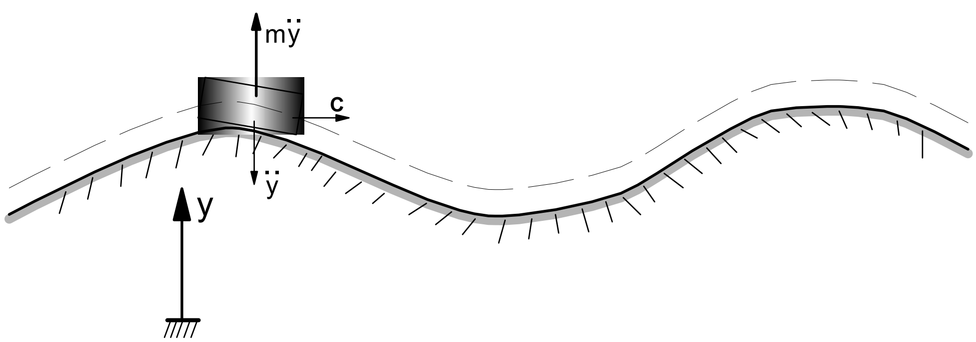


Figure 114. AMAA Represents the Mean Absolute Acceleration of a Mass following Perfectly the Pavement Surface.

The relative MAA (RMAA) represents the mean absolute acceleration of the body of the car. It is calculated the same way as AMAA, except that the acceleration y'' is of the body of the quarter car model with Golden Car parameters.

Calculation of AMAA and RMAA

MAA is defined as the mean absolute acceleration (curvature) of the profile. To make the absolute MAA (AMAA) independent of m and c, AMAA is defined simply as:

$$AMAA = \frac{1}{L}\int_0^L |y''| dx \tag{21}$$

The following equation can be used to calculate AMAA:

$$AMAA = \frac{1}{(N-1)D}\sum_{i=2}^{N-1}\left|\frac{y_{i+1} - 2y_i + y_{i-1}}{D^2}\right| D = \frac{1}{(N-1)}\sum_{i=2}^{N-1}\left|\frac{y_{i+1} - 2y_i + y_{i-1}}{D^2}\right| \tag{22}$$

where N is the total number of points in the profile and D is the sampling interval. RMAA can be calculated using the same equation if the elevation y is replaced by the displacement of the body of the car (sprung mass (m_s) in Figure 104), y_s.

AMAA and RMAA vs. IRI

To investigate the correlation between IRI and AMAA, both indices are calculated for ten profiles obtained from rod and level survey and the results are shown in Table 19. It is easy to observe that these two indices do not correlate well with each other. To investigate the observed lack of correlation between AMAA and IRI, the acceleration (curvature) histories for Profiles 2, 7, 8 and 9 are shown in Figure 115. The acceleration histories along with the corresponding spectra for Profiles 3, 7 and 8 are also illustrated in Figures 116 and 117. It is clearly observed that the magnitude of high peak accelerations and consequently, the calculated AMAA do not correlate well with IRI values. In comparison to IRI, AMAA is sensitive to higher frequency features of the profile. For example, while having a lower IRI, Profile 7 results in a larger AMAA value than Profile 8 (Figure 116). A comparison of spectra for these two profiles in Figure 116 shows that Profile 7 has much higher frequency energy than Profile 8. For similar reasons, Profiles 3 and 8 have the same AMAA but have very different IRI values (Figure 117).

RMAA, on the other hand, correlates very well to IRI. To investigate the correlation between RMAA and IRI, the histories for the acceleration of the body of the car corresponding to Profiles 2, 7, 8 and 9 are shown in Figure 118. It is clearly observed that, the body of the car filter filters out the high frequency features of the profile. Consequently, the acceleration amplitudes obtained from the vibrations of the body of the car have lower energy content over higher frequency wavebands. Therefore, RMAA is sensitive to the same wavelength range as IRI. This is the main reason for the good correlation observed between the two indices. The acceleration histories and the corresponding spectra for Profiles 7 and 8 are compared in Figure 119. Based on the obtained IRI values, Profiles 7 and 8 are categorized as moderate and rough pavements. Due to higher spectral amplitudes over a wider range, as observed in the spectra shown in Figure 119, Profile 8 has a higher RMAA value than Profile 7. The acceleration histories and spectra for body of the car vibrations based on simulations over Profiles 3 and 8 are compared in Figure 120. Based on IRI values, Profile 3 is very smooth and Profile 8 is rough, but they both yield the same AMAA. Looking at their acceleration spectra, Profile 8 has much more energy (higher spectral amplitudes) over a wider range of wavelengths and therefore shows a higher RMAA value.

The linear correlation between RMAA and IRI values are shown in Figure 121 (r^2=0.99) is observed between RMAA and IRI values.

Table 19. Comparison of AMAA and RMAA and IRI for a number of profiles obtained from rod and level survey.

Profile No.	Route	Section	W.P.	D (ft)	IRI (in/mi)	RN	AMAA (in/ft)	RMAA (in/ft)
1	55	S11	R	0.79167	64	3.34	21	0.64
2	55	S11	L	0.79167	53	3.54	18	0.55
3	55	S13	R	0.79167	74	1.88	25	0.72
4	55	S13	L	0.79167	73	1.32	27	0.69
5	195	S1	R	0.79167	144	1.50	73	1.36
6	195	S1	L	0.79167	123	1.69	71	1.18
7	195	S4	R	0.79167	114	2.73	31	1.16
8	18	S23	R	0.79167	186	2.53	25	1.90
9	18	S24	R	0.79167	313	1.05	59	2.77
10	18	S25	R	0.79167	337	0.55	65	2.96

From the physical standpoint, it is easy to argue that the newly introduced ride statistics (i.e. AMAA and RMAA) are more relevant to ride quality than some of the commonly used indices, like e.g. IRI. AMAA is a measure of energy of the profile roughness that can be, potentially, transmitted to the moving car causing vibrations. RMAA is a measure of energy of vibrations of the body of a car, calculated based on the simplified quarter-car or another car model. On the other hand, IRI represents a cumulative motion of the car suspension system (relative motion of the car axle and body). To adopt AMAA and RMAA, or other indices, as alternative ride indices, their applicability and relevance should be further evaluated by conducting more extensive experiments. Such experiments should include MPR on a larger set of profiles of different smoothness categories. A carefully designed mean panel rating experiment will provide the necessary basis to compare various available ride indices. In absence of it, any comparison in practical terms would be pretty much speculative.

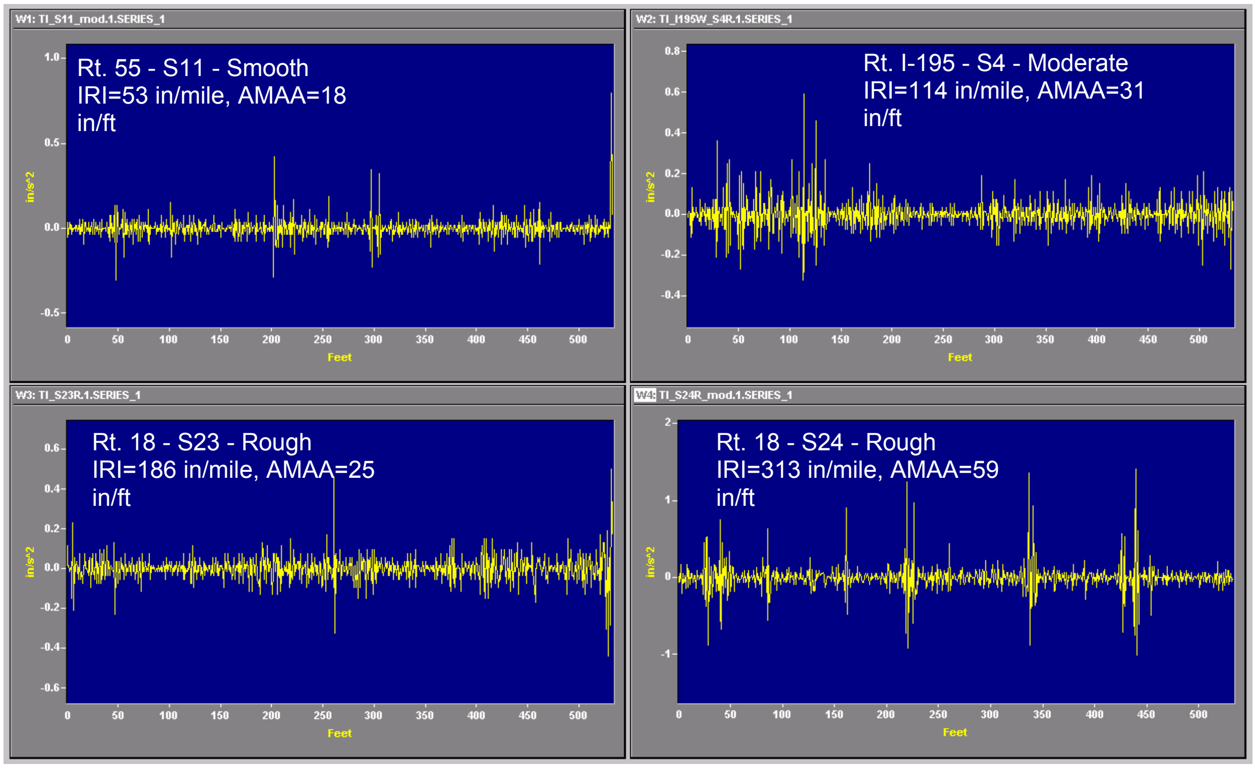


Figure 115. Acceleration Histories for Profile 2, 7, 8 and 9.

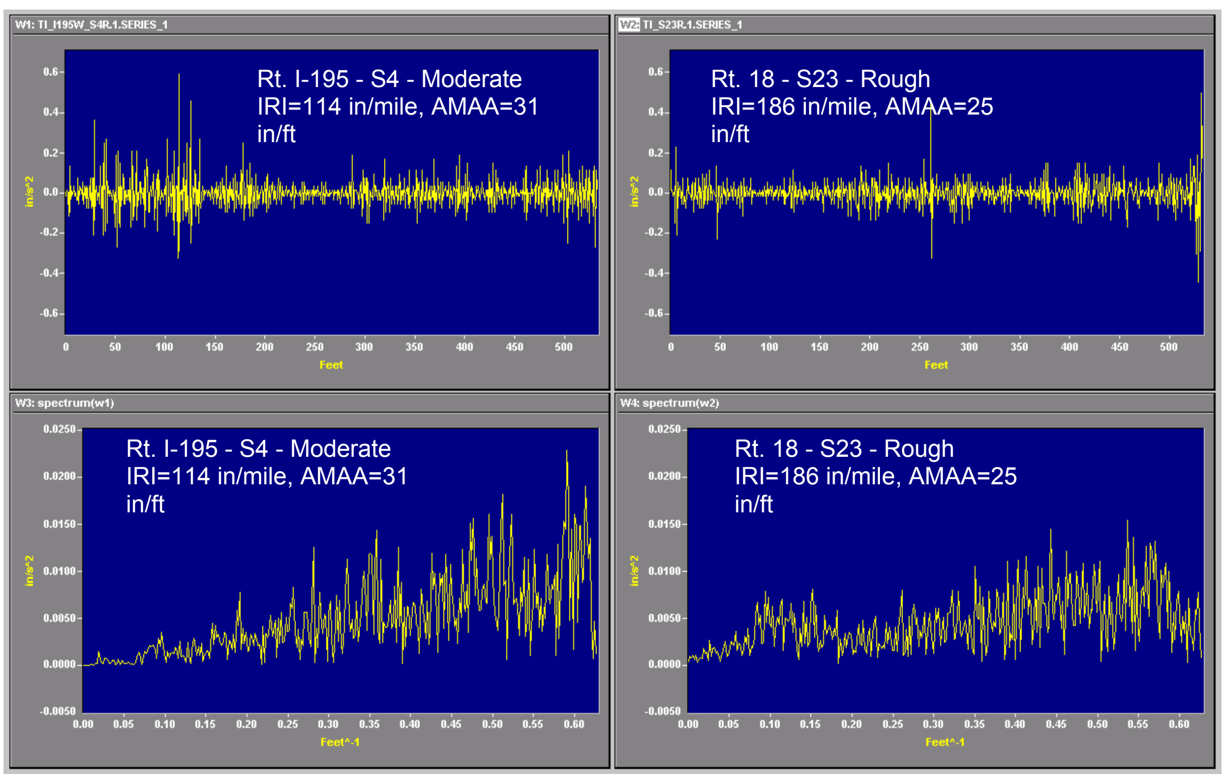


Figure 116. Acceleration Histories and Spectar for Profiles 7 and 8.

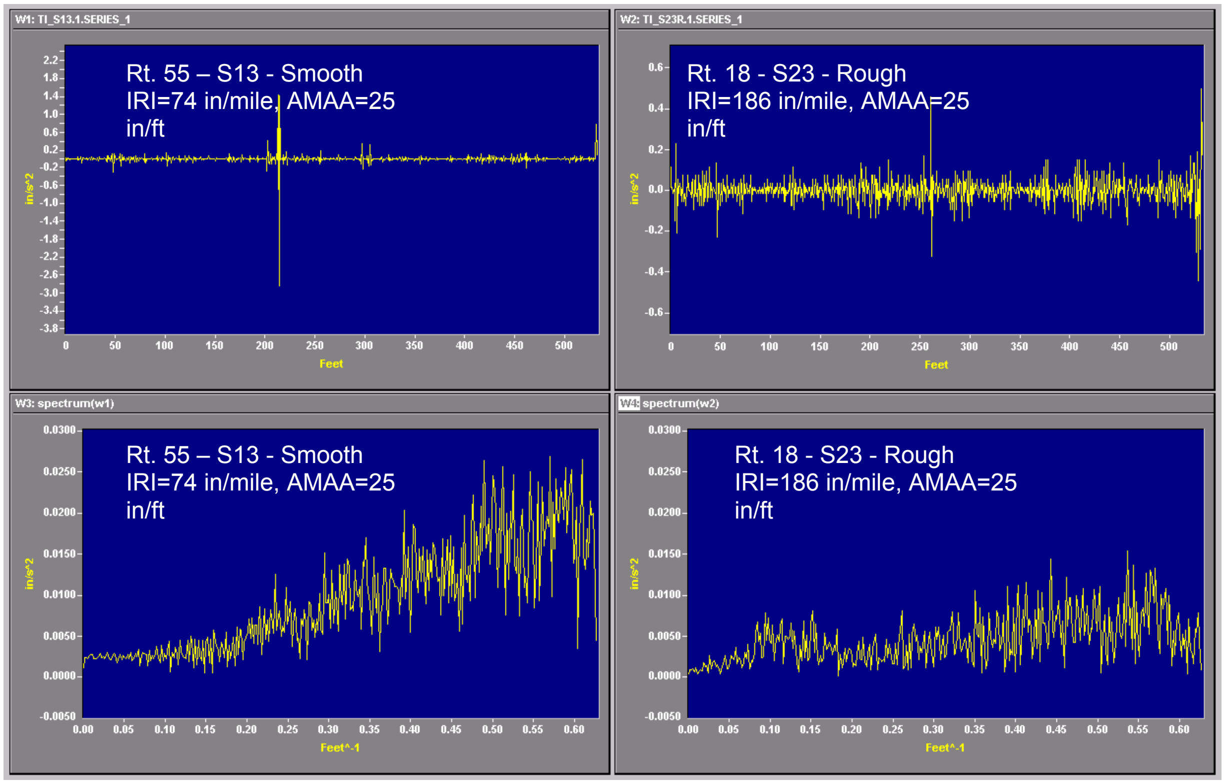


Figure 117. Acceleration Histories and Spectar for Profiles 3 and 8.

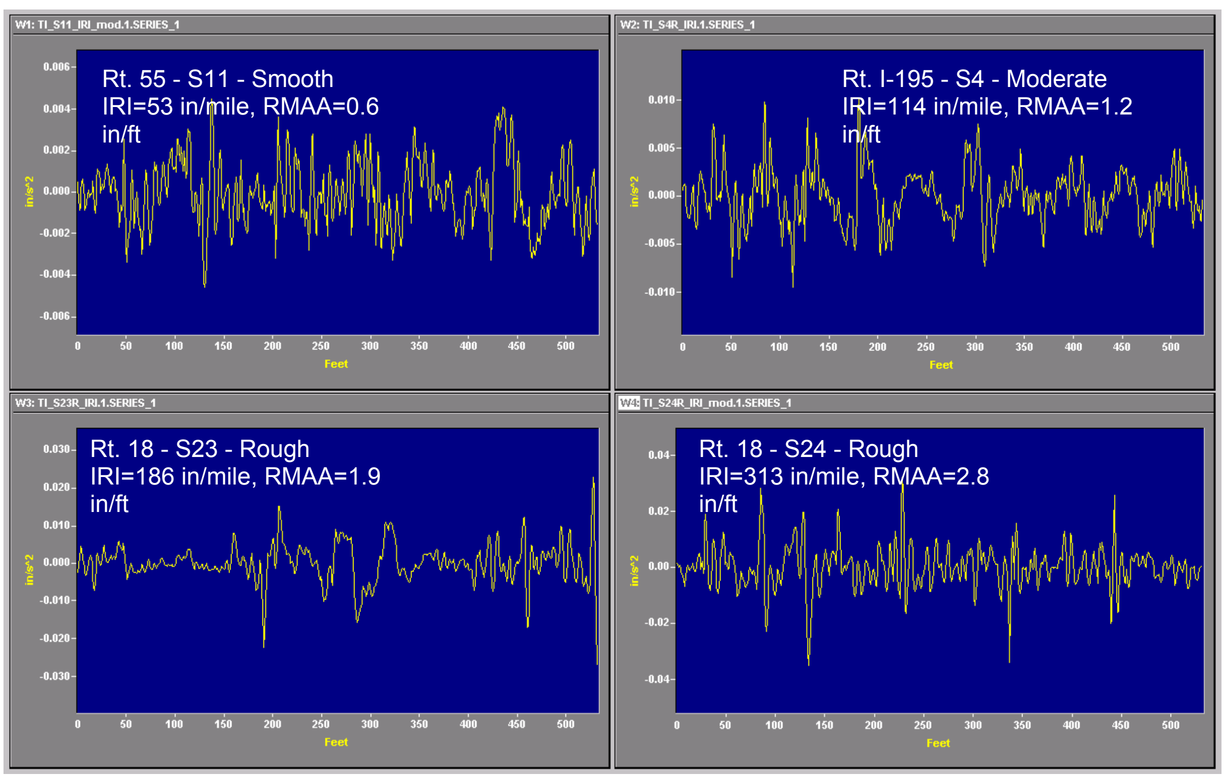


Figure 118. Acceleration histories for Profiles 2, 7, 8 and 9

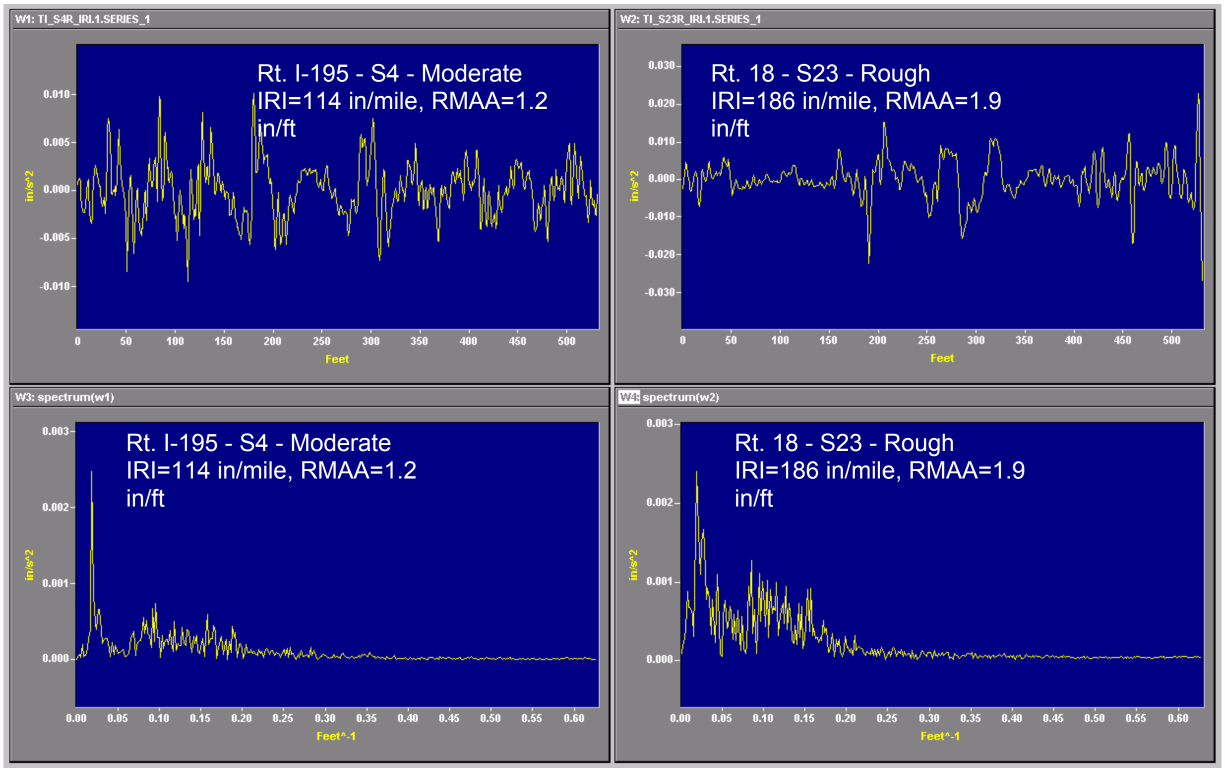


Figure 119. Acceleration histories and spectar for Profiles 7 and 8

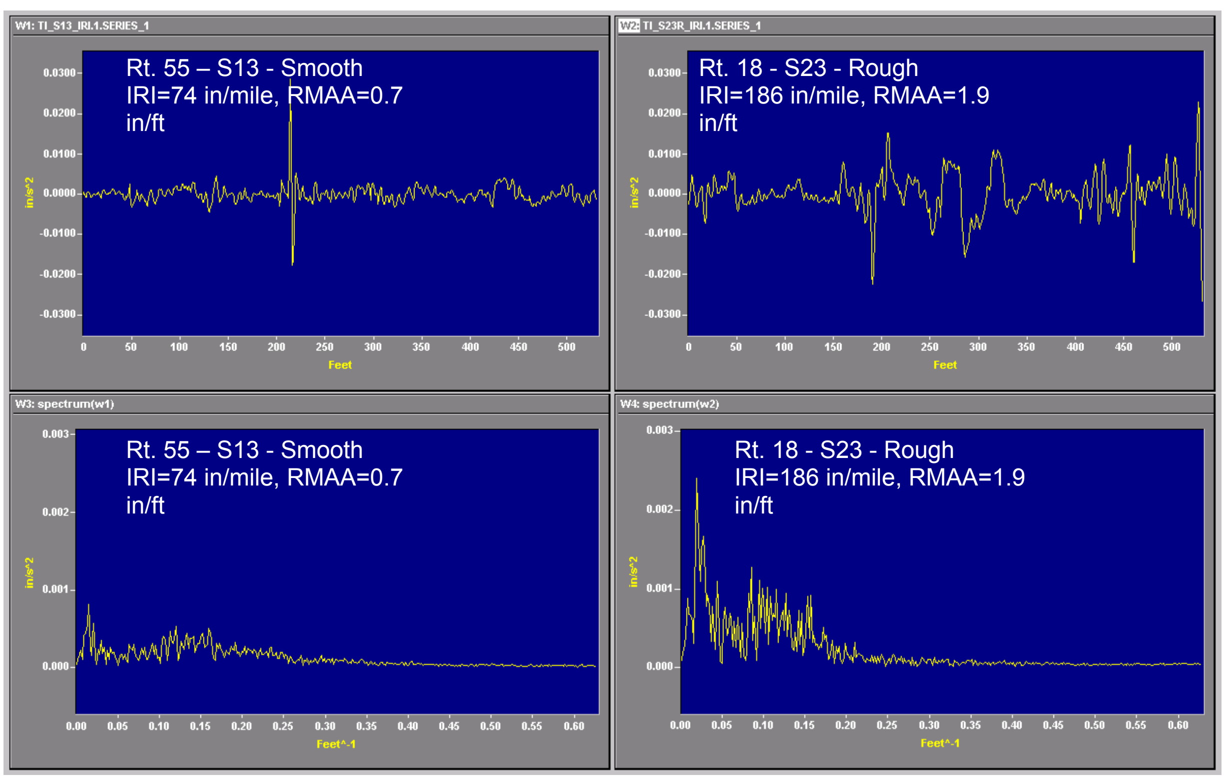


Figure 120. Acceleration histories and spectar for Profiles 3 and 8

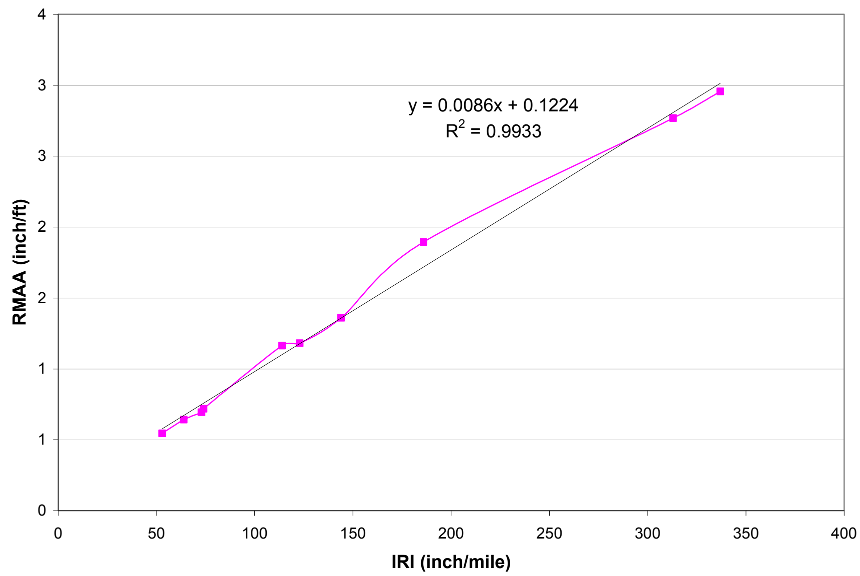


Figure 121. Correlation between IRI and RMAA.

ADVANCED PROFILE ANALYSIS

Application of a number of advanced analysis techniques in evaluation of pavement smoothness is investigated in this study. A brief overview of continuous and discrete wavelet transforms is given. Continuous wavelet transforms (CWT) can be used to provide a two-dimensional distance-frequency picture of the one-dimensional longitudinal profile. The changing distribution of the profile energy among various wave bands along the length of the profile can be viewed in the wavelet-based 2D distance-frequency images. This can be used to spot the rough spots or investigate the existence of repeated waves throughout the profile. Discrete wavelet transforms (DWT), on the other hand, are used to decompose the profile. The multiresolutional decomposition acts as a simultaneous bandpass filtering operation with certain characteristics. The energy of the decomposed profile at each decomposition level can be easily calculated. Finally, a number of issues concerning the filtering operations commonly used in pavement smoothness applications are discussed and a number of alternative filtering schemes are proposed.

Continuous Wavelet Transforms (CWT)

Any pavement profile can be broken down into a linear combination of sinusoids of different frequencies (wavelengths), amplitudes, and phases (Figure 122). Fourier transform is commonly employed to calculate the amplitude and phase of each profile harmonic. For an arbitrary N-point set of profile elevation points $p(n)$ obtained at sampling interval of D, complex coefficients of Fourier transform at every frequency f, $P(f)$, can be obtained by the following equation

$$P(f) = \sum_{n=0}^{N-1} p(n) e^{-2\pi i f D n} \qquad (1)$$

It is also useful to think of Fourier transform as a change in the function space, from the spatial domain, where the bases are unit vectors to a different domain, where the bases are harmonics of different frequencies. It should be noted that, because of the summation over the entire length of the profile (equation 23), all data points in the profile contribute to the magnitude of the Fourier coefficient at every frequency. In other words, Fourier analysis provides averaged spectral coefficients over the length of the profile. If the various frequency features of a profile were distributed uniformly over its length (as shown schematically in the synthetic profile in Figure 122), Fourier transform would have been an ideal analysis tool for extracting the frequency content of the profile. However, the distribution of frequency features throughout the profile is usually far from uniform. Using Fourier analysis, it is impossible to extract any information on the location and the extent of any short-lived feature of the profile. Wavelet transforms, by virtue of their scaling and translating basis, can provide a two-dimensional distance-frequency map of the profile in which, both the location and frequency information of various roughness features of the profile can be simultaneously viewed.

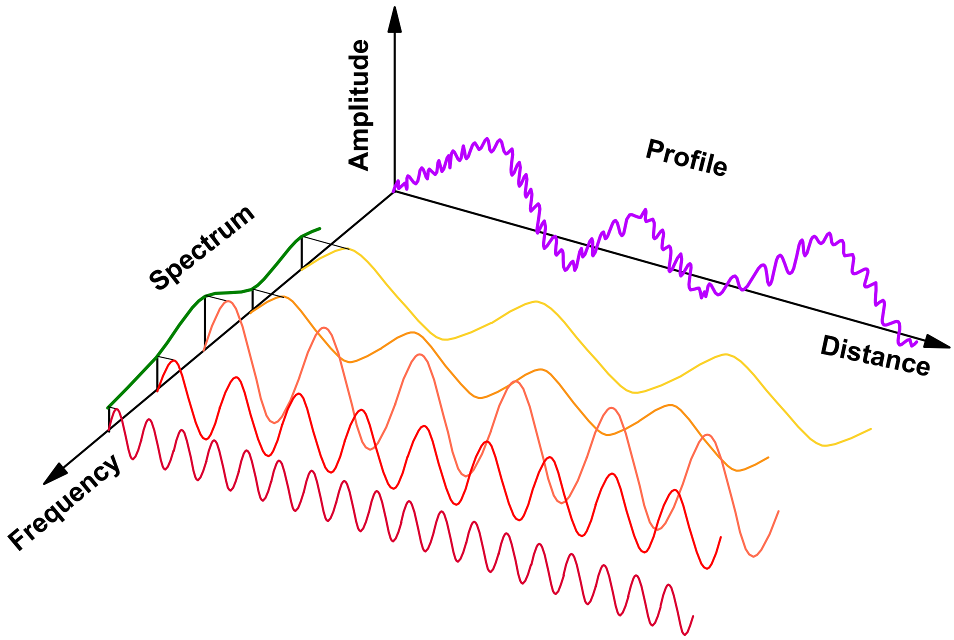


Figure 122. A Pavement Profile is a Superposition of Harmonics of Different Frequencies, Amplitudes and Phases.

A wavelet transform decomposes the discrete profile $p(n)$ into a linear combination of wavelets (Figure 121). Wavelets are scaled and translated versions of a single function called "mother wavelet" $\Phi(x)$ obtained according to the following equation:

$$\Phi_{a,l}(x) = \frac{1}{\sqrt{a}}\Phi(\frac{x}{a} - l) \quad (2)$$

where $\Phi_{a,l}(x)$ is the analyzing wavelet at scale a and location l. Dilated and translated wavelets define a new basis for a function space, a wavelet basis. What makes the wavelet basis interesting is that, unlike sinusoidals, which make the Fourier basis, wavelets are quite localized in the space; simultaneously, like sinusoidals, wavelets are quite localized in the frequency domain. In other words, wavelets act as bandpass filters in both spatial and frequency domains. Dilation of wavelets changes their bandwidths in the both domains. Depending on the value of scale a, $\Phi_{a,l}(x)$ is stretched/contracted horizontally while compressed/expanded vertically. Longer wavelets have wider spatial and narrower frequency bandwidths. Shorter wavelets, on the other hand, have narrower spatial and broader frequency bandwidths. Using a wavelet transform, the profile is expanded in terms of a set of wavelet varying bandwidth basis. Therefore, a wavelet transform can capture both short-lived high frequency and long-lived low frequency features of the profile. This characteristic of a wavelet transform makes it a more appropriate tool for analysis of nonstationary signals, such as profiles.

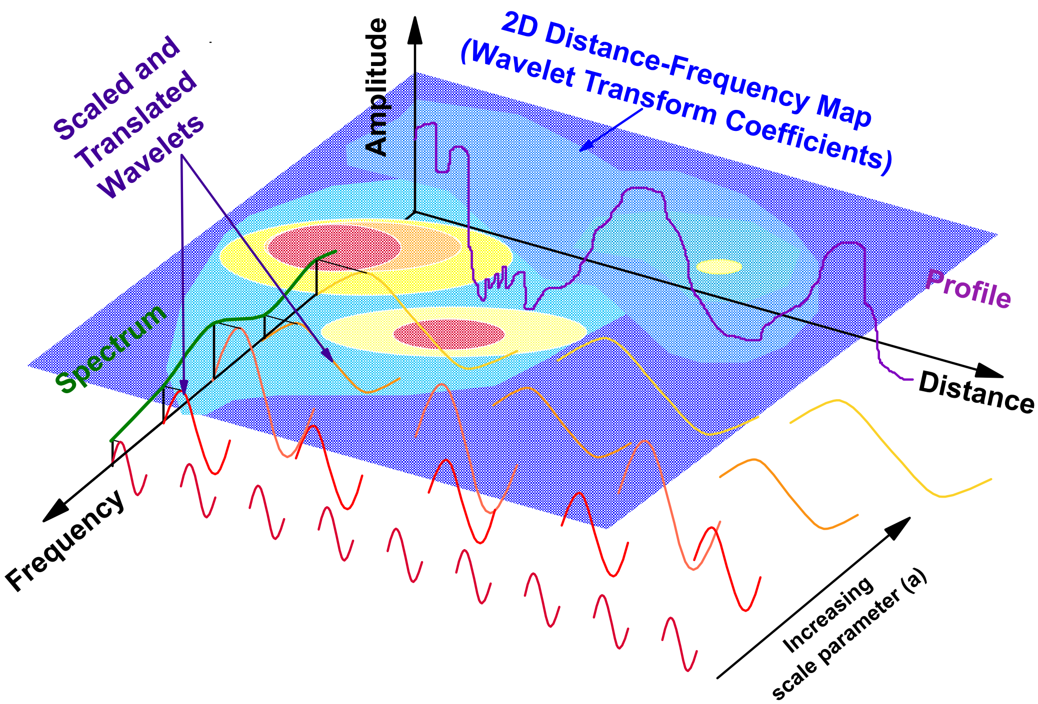


Figure 123. Wavelet Transform Decomposes the Profile into a Linear Combination of Scaled and Translated Wavelets.

The CWT is defined as a convolution between a signal and a set of dilated and translated wavelets $\Phi_{a,l}(x)$ over a finite range of scale values:

$$W_{a,l} = \int_{-\infty}^{\infty} p(x)\Phi^*{}_{a,l}(x)dx \qquad (3)$$

where * indicates the complex conjugate. If the "mother wavelet" is an orthogonal function, the dilated and translated wavelets $\Phi_{a,s}(x)$ make an orthogonal basis. Orthogonality of the analyzing wavelets reduces the computational effort behind the analysis. Unlike sines and cosines, which define a unique Fourier transform, there is not one unique single set of wavelets; in fact, there are infinitely many possible sets. Roughly, different sets of wavelets differ in terms of their localization in space and their smoothness. The analyzing wavelets are normally chosen based on the properties of the signal to be analyzed and the type of information that needs to be extracted from the signal. DAUB6 [31] from the Daubechies class of wavelets have been adopted for this study.

To demonstrate the application of CWT in locating rough spots, a sample profile (Route 18, S23, RWP) obtained from rod and level survey is analyzed and the results are presented in Figure 124. Prior to the analysis, the geometry curve is filtered out using a filtering operation based on Spline interpolation scheme (This process is discussed in detail in the next section). The resulting "decurved" profile is shown in Figure 124a. The continuous wavelet map corresponding to this profile is generated and presented in Figure 124b. It can be observed that, the location and extension of every frequency feature of the profile can be spotted in the wavelet map.

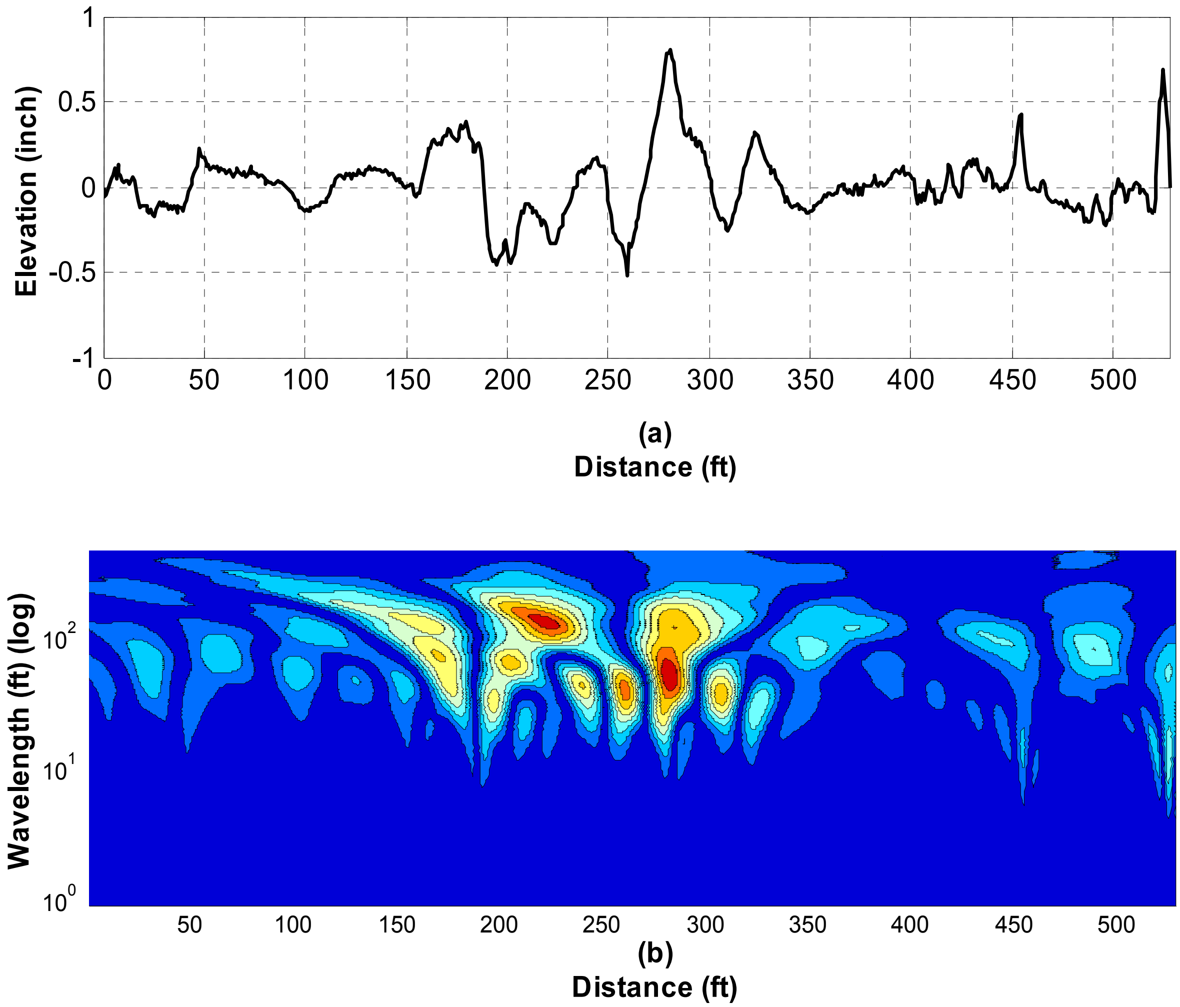


Figure 124. CWT for a Sample Profile.

Discrete Wavelet Transforms (DWT)

Discrete wavelet transforms are very similar to continuous wavelet transforms. The only difference is that, in the case of the DWT, only a special subset of scale parameters (e.g. $a = 2^s$ where s is an integer) is considered for the analysis. Discrete wavelet transform with orthogonal basis is numerically calculated using a so-called pyramidal algorithm. This algorithm is schematically presented in Figure 125. For a 2^L-point profile, the process is completed in L steps or levels. At the first level, the profile is divided into a coarse low frequency a_1 (averaged) and a fine high frequency d_1 (detailed) component. The a_1 component is further decomposed into a low frequency a_2 and high frequency d_2 (detailed) component in the second level. The procedure is repeated until a_L and d_L are obtained at the L th level. After the decomposition is completed, the profile can be expressed as the following linear superposition:

$$p = a_L + d_L + d_{L-1} + ... + d_2 + d_1 \quad (4)$$

The DWT decomposition can be viewed as a simultaneous low-pass and high-pass filtering of the profile at every level i. The cut-off frequency of the simultaneous filters at each subsequent level of decomposition is decreased by one octave. The outcome of the high-pass filtered portion is saved as the detailed component d_i and the low-pass filtered portion a_i is filtered further in the following levels. Consequently, d_1 renders the highest octave band of the profile and d_2, d_3,…,and d_L consist of the subsequent lower octave bands

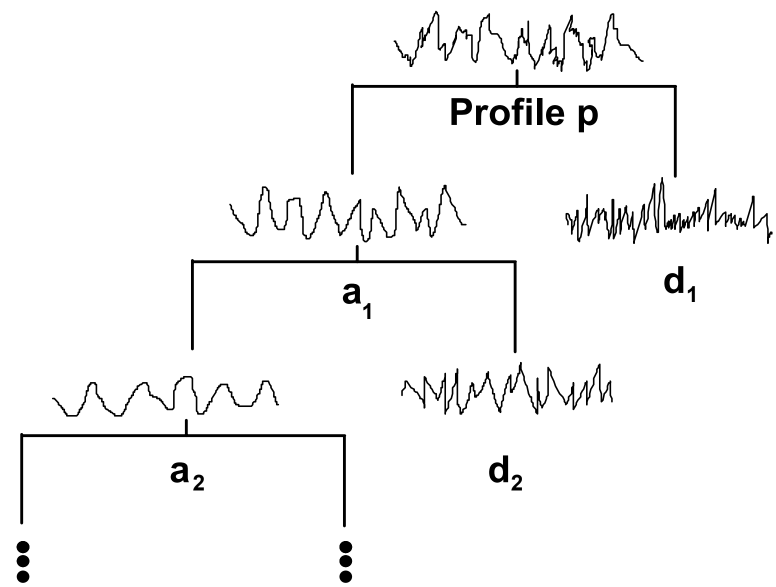


Figure 125. Schematic Diagram of DWT Decomposition Algorithm.

DAUB6 [(31)] from the Daubechies class of wavelets have been adopted for this study. Since DAUB6 wavelets are orthogonal and therefore, the analysis can be carried out using the described pyramidal algorithm.

Multiresolution Analysis of Sample Pavement Profiles using Discrete Wavelet Transform

To demonstrate advantages of a wavelet-based multiresolution analysis over the traditional PSD analysis, the results of the wavelet analysis for three sample pavement profiles are presented. The profiles are obtained by conducting rod and level surveys on certain sections of Route 55, Interstate 195 and Route18 (Table 20). Each section is about 0.1 mile long and the shots are taken at 9.5-inch intervals.

PSD estimations of these profiles are presented in Figure 126. In all three cases, the variation in surface elevations is of a much smaller order than the roadway vertical curve elevations. Prior to PSD calculations, the effect of roadway geometry should be eliminated from the profile. Otherwise, the sharp discontinuities at the end of the profile introduce artifacts in the PSD estimation, commonly known as edge effects. The vertical curve for profile 1 is parabolic, while the other two profiles have linear trends. Having the measured profile data, the vertical curve of profile 1 was estimated from the available typical highway vertical parabolic curves and was subtracted from the profile. The linear trends for the other two profiles were calculated from a simple regression analysis and both profiles were detrended. In the next step, the "filtered" profiles were zero padded on both ends. These filtering operations are discussed in the next section. Finally, the PSD functions were estimated using Fourier transform and are presented as a function of spatial frequency or wave number.

To compare the level of roughness associated with each profile, the IRI [15,17] was calculated for each profile and the IRI values given in Table 20. Based on the calculated IRI values, Profile 1 falls in the "very smooth" category of roughness. Profile 2 can be described as "smooth to moderate" and profile 3 can be regarded as a "moderate to relatively rough" pavement section.

Table 20. List of Analyzed Pavement Profiles.

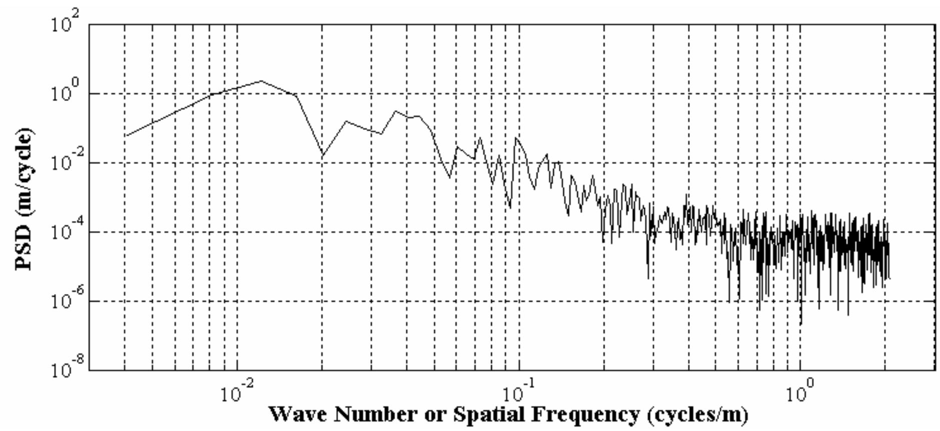
Profile	Route No.	Section	Wheel Pass	IRI (m/km) (in/mi)
1	55	S11	Left	0.84 (53)
2	195	S1	Left	1.94 (123)
3	18	S23	Right	2.94 (186)

A comparison of PSD estimations for these three profiles indicates that the smoother pavement (profile 1) has the lowest PSD amplitudes over the entire range of Nyquist interval. Despite being categorized as a rougher pavement, profile 3 has lower PSD amplitudes over high frequencies (wavelength < 1m) than profile 2. The two profiles have approximately the same PSD amplitudes over the range of frequencies from 0.6 to 1 cycles/m (wavelengths of 1 to 1.67m). Over the lower range of frequencies (0.03 to 0.6 cycles/m or wavelengths of 1.67 to 33.33m), profile 3 has higher PSD amplitudes. The two profiles have the same PSD amplitudes for frequencies between 0.02 and 0.03 cycles/m. The very low frequency portion of the profile PSD is highly sensitive to the procedures used for filtering the effects of geometry and therefore is not considered for comparisons.

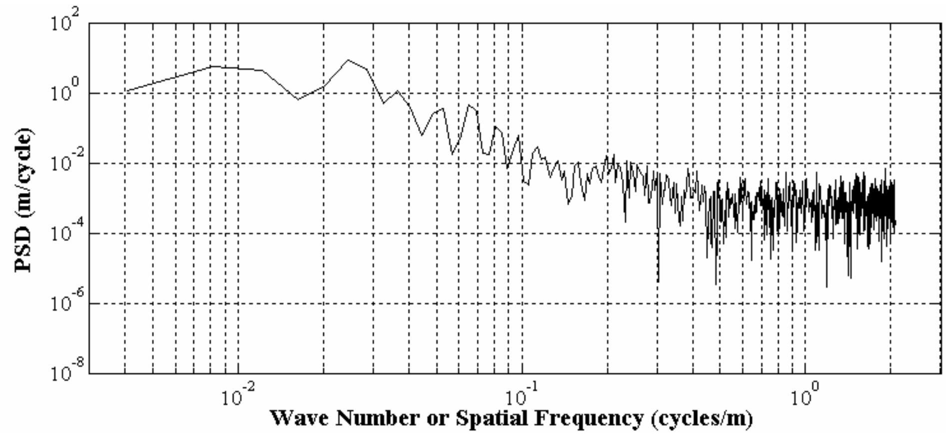
To relate the wave number or spatial frequency k (cycles/m) to physical frequency of vibrations f (Hz) experienced by the passengers, one needs to assume the velocity of the vehicle (V). The relationship is given in the following simple equation:

$$f = Vk \tag{5}$$

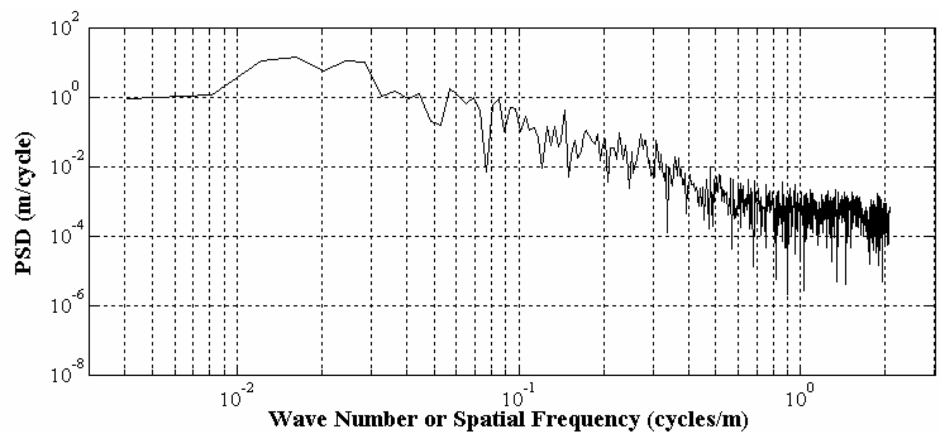
For example, to translate the critical range of frequencies with respect to passengers' comfort at a highway speed, one needs to divide the given frequency range of 4 to 13Hz [19] by the velocity of 65 mph. This gives the spatial frequency range of 0.14 to 0.45 cycles/m. The concentration of energy of the profile in this frequency range (or any other frequency bandwidth) can be easily characterized by its PSD estimation. However, by studying the PSD functions alone, it is impossible to locate or determine the extent of a specific portion of the profile where a certain frequency (wavelength) is dominant. Locating the defects or "rough spots" on the profile is especially important in decision-making related to pavement surface maintenance or bonus/penalty assignments to contractors.



(a)



(b)



(c)

Figure 126. PSD Estimations for (a) Profile 1 (Rt55 – S11, LWP), (b) Profile 2 (I195 – S1, LWP), and (c) Profile3 (Rt18 – S23, RWP)

The DAUB6 wavelet-based 9-level decompositions of the profiles are presented in Figures 129 to 131. There is no need to filter the profile prior to the analysis. The first level of analysis consists of decomposition of the profile into a low frequency component a_1 and a high frequency component d_1. In the next level, a_1 is decomposed into a lower frequency component a_2 and a higher frequency component d_2. This process is repeated in the subsequent levels. Simple and numerically efficient algorithms are available for discrete wavelet analysis, which provide the whole array of decomposition components simultaneously [(32).] The number of data points in the profile determines the maximum number of levels of decompositions. There are 668, 668, and 670 data points in profiles 1, 2, and 3 respectively. The largest power of two, which is still less than 668, is 512 or 2^9. Therefore, there can be at most 9 levels of decomposition. The unfiltered profile is shown at the top of each figure. The last remaining low frequency component of the profile a_9 and the successive higher frequency components, namely $d_9, d_8, \ldots, d_1$ are also presented. Every decomposed component of the profile obtained through discrete wavelet analysis covers an octave frequency bandwidth. Together, they cover the entire Nyquist interval. The frequency bandwidths (range of wavelengths) corresponding to all components are given in Table 21.

Wavelet-based multiresolution decomposition of profiles, as illustrated in Figures 127 through 129, can be used effectively as a diagnostic tool. It is clear why it was not necessary for a profile to be filtered before the analysis. The effect of geometry is included in the last remaining components and therefore is automatically removed. The decomposition of profile 1 in Figure 127 indicates that energy in different wavebands is well spread throughout the length of the profile. The decomposed components d_3 and d_4 cover the frequency range to which humans are most sensitive. No anomalies are observed in either component. These observations confirm the fact that the profile is very smooth. This profile was earlier categorized as “very smooth” on the basis of its very low IRI value.

A quick comparison of Figures 127 and 128 is sufficient to conclude that profile 2 has a higher roughness. The energy of the profile in higher frequency components (d_6 to d_1) is significantly higher. However, the energy is evenly distributed throughout the profile. The findings of some correlation studies [(14,27)] indicate that the car passengers are most sensitive to frequencies higher than the range of frequencies given by International Standard ISO 2631-1:1997. It has been concluded that the presence of some short-lived disturbances in the profile has a significant effect on the ride quality of the pavement. Pavement features causing these pulse-like defects include cracks, patches, spalls, slab faulting, joints, and reflection cracks [(14)]. Presence of such high frequency features can be both detected and located using the wavelet analysis.

The discrete wavelet decomposition of profile 3 is illustrated in Figure 129. Unlike the two previous profiles, the energy of profile 3 is not distributed over the entire length of the profile. Instead, the energy of the profile in frequency components d_6 to d_1 is concentrated over a portion of the profile extending from about 160 to 300 ft. In such circumstances, where the roughness is not uniform throughout the length of the profile, wavelet analysis is superior to PSD analysis or any averaged roughness index such as IRI. A “rough spot” can be clearly located using the proposed diagnosis method. In more severe situations, when based on roughness indices or the results of PSD analysis some remedial actions need to be taken to improve the pavement condition, or the amount of bonuses/penalties needs to be defined, the knowledge of roughness distribution throughout the pavement section is extremely valuable.

In addition to the above applications, discrete wavelet analysis can be useful in development of new ride quality indices. In other studies, to develop many of the available ride indices, panel ratings were correlated to the RMS roughness level over various wavebands, calculated from PSD functions [(21).] The energy or other related statistics (such as RMS values) in every waveband can be easily calculated using discrete wavelet decomposition. Having the discrete wavelet decomposition of profiles, it is easier to divide them into sections of uniform roughness. The uniformity of the roughness improves the mean panel ratings and consequently the quality of the developing ride index. The energy of the profile in every waveband can be easily calculated by integrating the corresponding decomposed component. The calculated energies in each waveband can then be correlated to the mean panel ratings.

Table 21. Bandwidth of Wave Transform Decomposed Components.

Component	a_9	d_9	d_8	d_7	d_6
Frequency Bandwidth (cycles/m)	0 – 0.004	0.004 – 0.008	0.008 – 0.016	0.016 – 0.032	0.032 – 0.065
Wavelength Range (m)	250 - ∞	125 - 250	62.5 - 125	31.25 – 62.5	15.62 – 31.25
Component	d_5	d_4	d_3	d_2	d_1
Frequency Bandwidth (cycles/m)	0.065 – 0.129	0.129 – 0.259	0.259 – 0.518	0.518 – 1.306	1.036 – 2.072
Wavelength Range (m)	7.81 – 15.62	3.91 – 7.81	1.95 – 3.91	0.98 – 1.95	0.49 –0.98

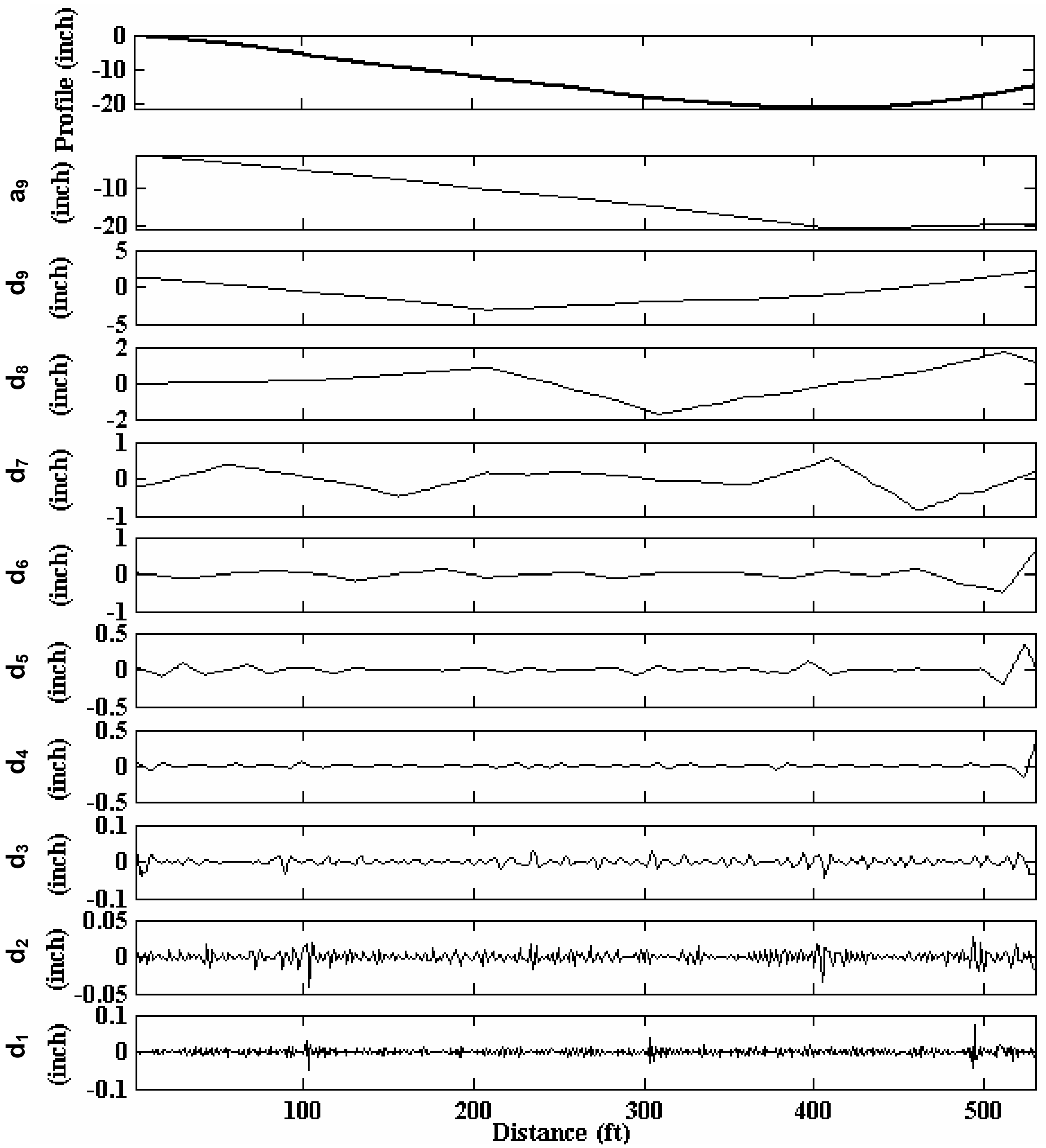


Figure 127. DWT Decomposition for Profile 1.

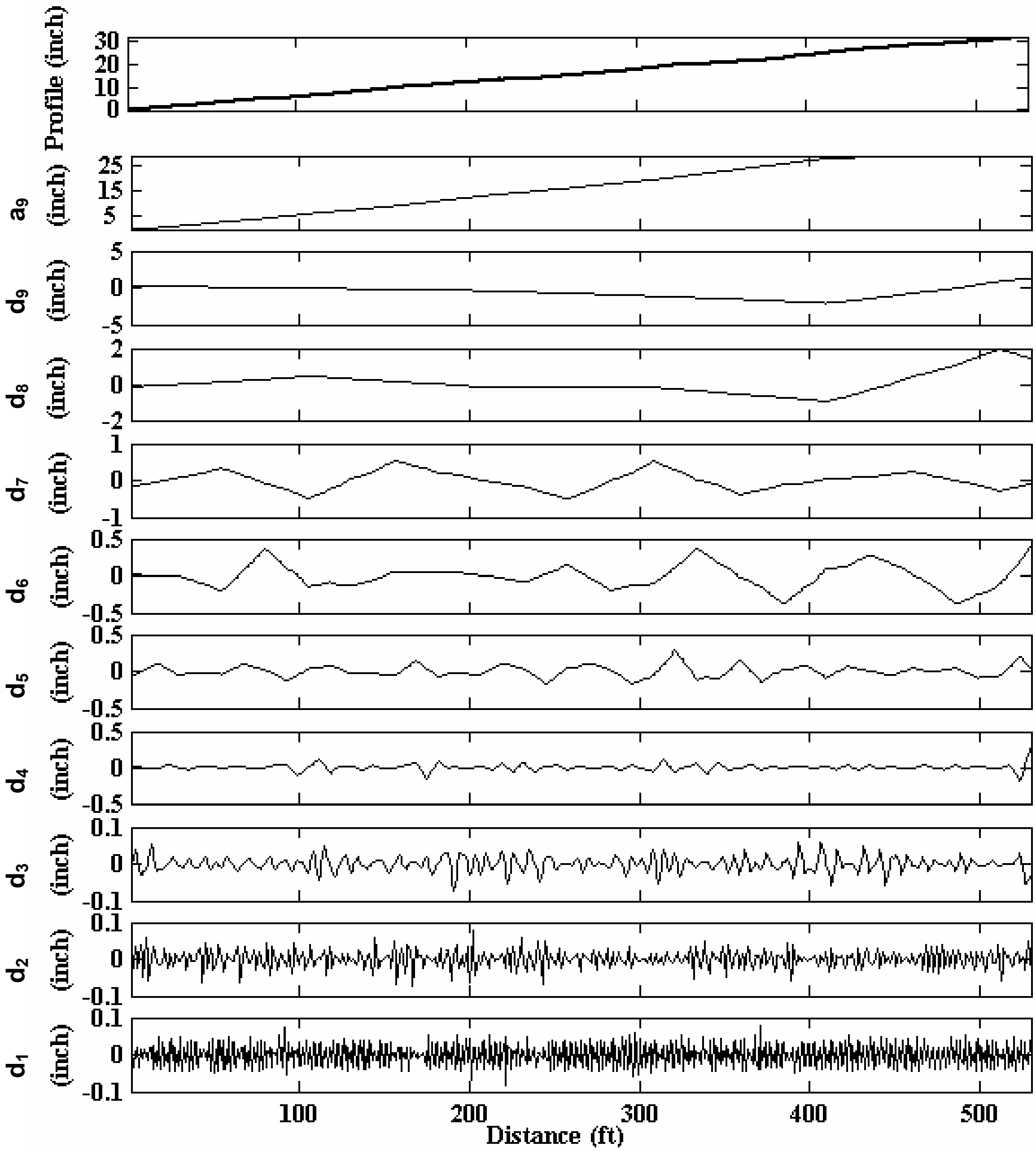


Figure 128. DWT Decomposition for Profile 2.

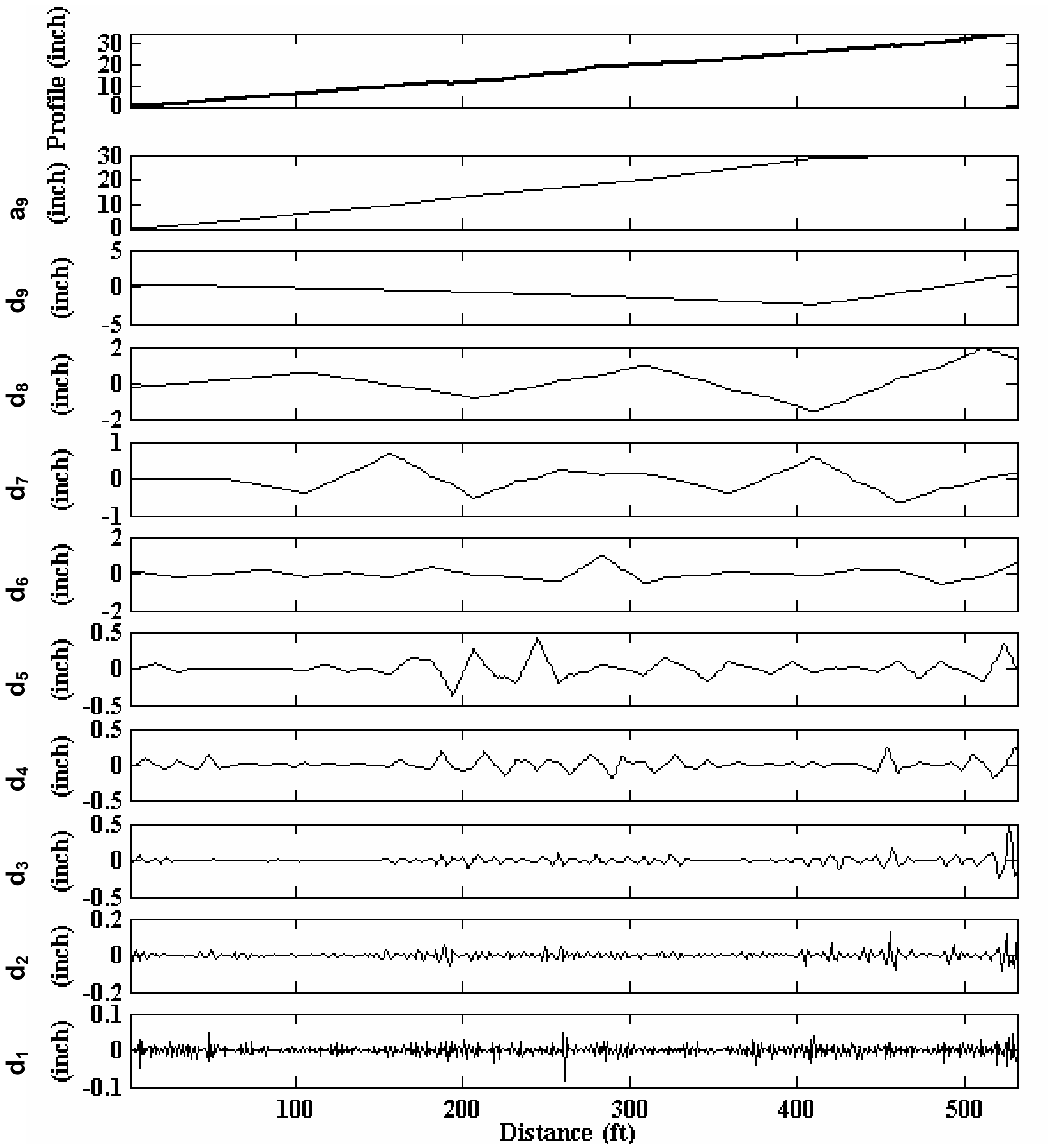


Figure 129. DWT Decomposition for Profile 3.

Filtering Operations

A true pavement profile consists of a low frequency trend coming from the geometry of the road superimposed by high frequency roughness fluctuations. Pavement profiles, as measured by profilers, are not true profiles. They are affected by profiles characteristics. Some of these effects are caused by manufacturer's built-in pre-filters (e.g. high-speed profilers), while others result from the operation of the profiler itself (e.g. RSE). To remove the low frequency geometry trend or investigate the effects of pre-filters on calculated ride indices, it is necessary to filter the profile. A number of issues concerning the common practice of Butterworth filtering are pointed out and an alternative filtering operation is proposed.

Butterworth Filters

It is customary to filter the profiles using Butterworth filters. A Butterworth filter is schematically shown in Figure 130. In frequency domain, a filtering operation is equivalent to scaling each spectral amplitude of the profile by the amplitude of filter at the same frequency. In spatial domain, a filtering operation is equivalent to convoluting the profile and the window corresponding to the filter. As it can be seen in Figure 130 a Butterworth filter has several controlling parameters called filter specifications. Varying filter specifications changes the shape of the filter and therefore, the spectral characteristics of the resulting filtered profile. These effects are discussed here.

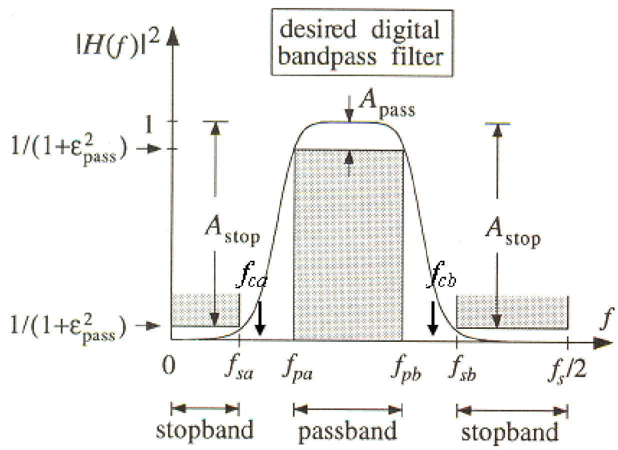


Figure 130. Butterworth Filter Specifications.

For a bandpass Butterworth filters, the specifications include: minimum and maximum frequencies defining the bandpass (f_{pa}, f_{pb}), bandstop frequencies (f_{sa}, f_{sb}) and passband and stopband attenuations (A_{pass}, A_{stop}). The filters are usually characterized by their order $N(f_{pa}, f_{pb}, f_{sa}, f_{sb}, A_{pass}, A_{stop})$, which is a function of all filter specifications. Smaller attenuations over the passband A_{pass}, larger stopband attenuation A_{stop} and smaller transition width ($|f_{pa} - f_{sa}| or |f_{sa} - f_{sb}|$) results in better filters of higher order (larger N). In Figure 130, f_{ca} and f_{cb} represent minimum and maximum cut-off frequencies for a Butterworth filter:

$$f_{ca} = \frac{f_{sa} + f_{pa}}{2}, f_{cb} = \frac{f_{pb} + f_{sb}}{2} \qquad (6)$$

Therefore, depending on the filter specifications, Butterworth filters of the same cut-off frequencies (identical f_{ca} and f_{cb}) may have different shapes and therefore, different filtering effects. To illustrate these effects, Profile 9 (Route 18, Section 24, RQP) is filtered by Bandpass Butterworth filters of different specifications and the results are presented in Figures 131 to 133. All filters used to generate the filtered profiles in all these figures have the same cut-off wavelengths of 10 and 250 ft. The bandpass range for the filter shown in Figure 131 (a) is between 15 and 200 ft while the bandpass for the filter shown in Figure 132(a) ranges from 12.5 to 225 ft. For both filters, $A_{pass} = 1$ and $A_{stop} = 5$. Obviously, the filters shown in Figures 131a and 134a have different shapes and because of its narrower transition width, the filter shown in Figure 132a has higher order. Obviously, the resulting filtered profiles shown in Figures 131c and 132b are not the same and have different spectral characteristics. The filter shown in Figure 133a has the same bandpass as the one in Figure 131a (15 to 200 ft). However, it has lower attenuation over its bandpass ($A_{pass} = 0.5$) and larger stopband attenuation ($A_{stop} = 20$). As expected, imposing the new attenuation requirement results in a higher order filter ($N = 8$) shown in Figure 133a. The filtered profile presented in Figure 133b is different from those shown in Figures 131c and 132b. As it can be easily concluded, depending on the other design parameters involved, Butterworth filters with of the same cut-off wavelengths may result in quite different filtered profiles.

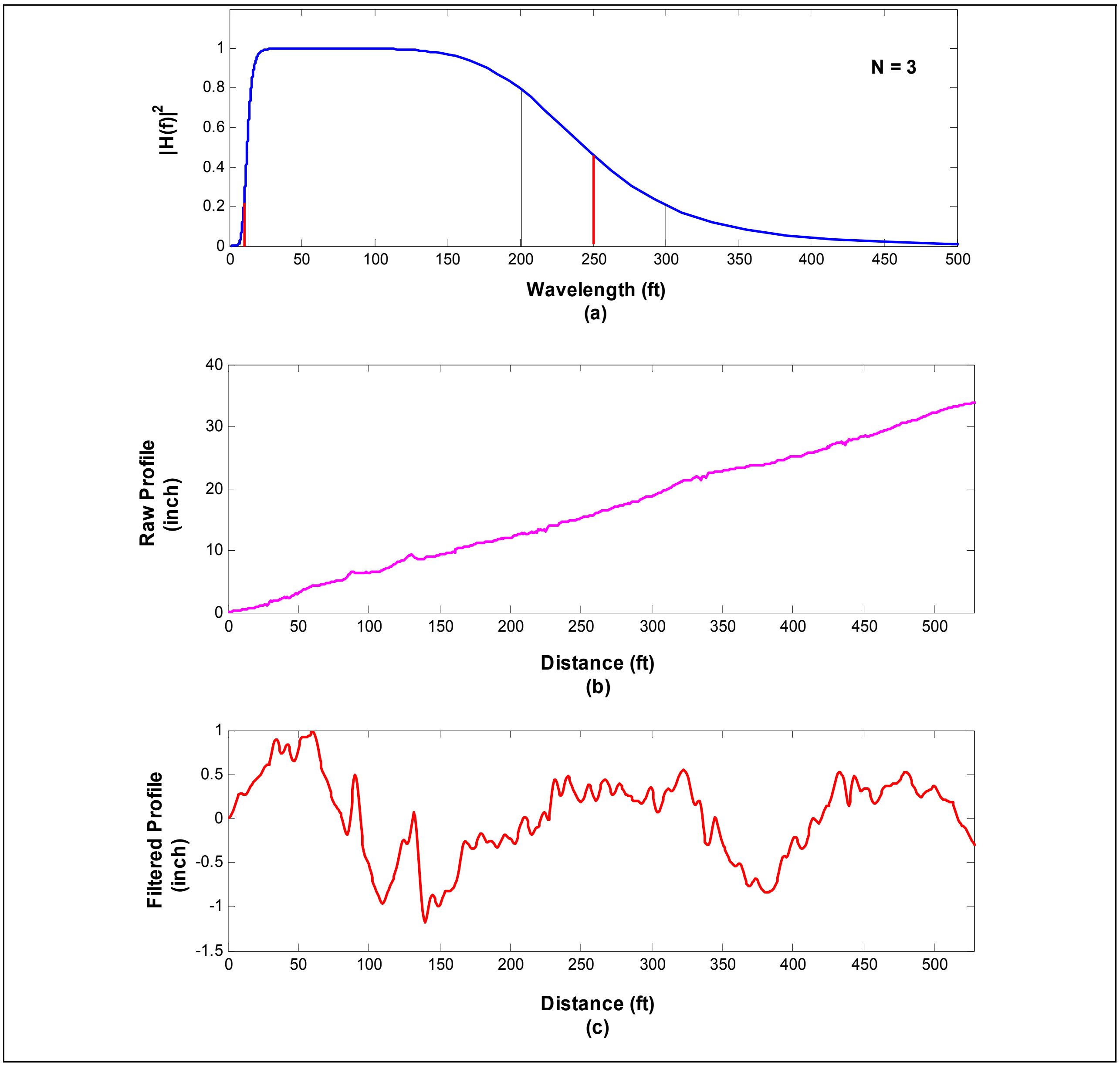


Figure 131. (a) Filter, (b) Raw Profile and (c) Filtered Profile.

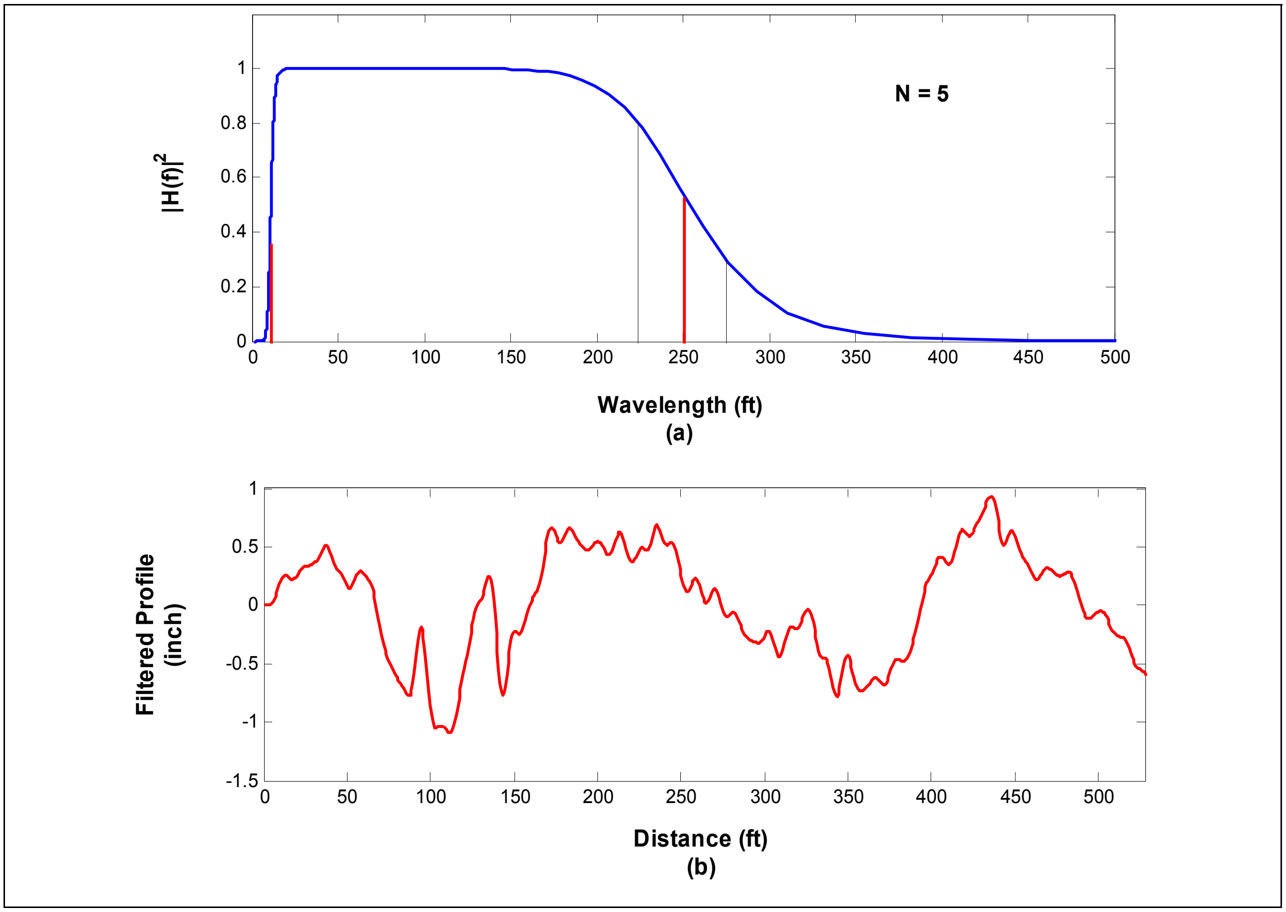


Figure 132. (a) Filter and (b) Filtered Profile.

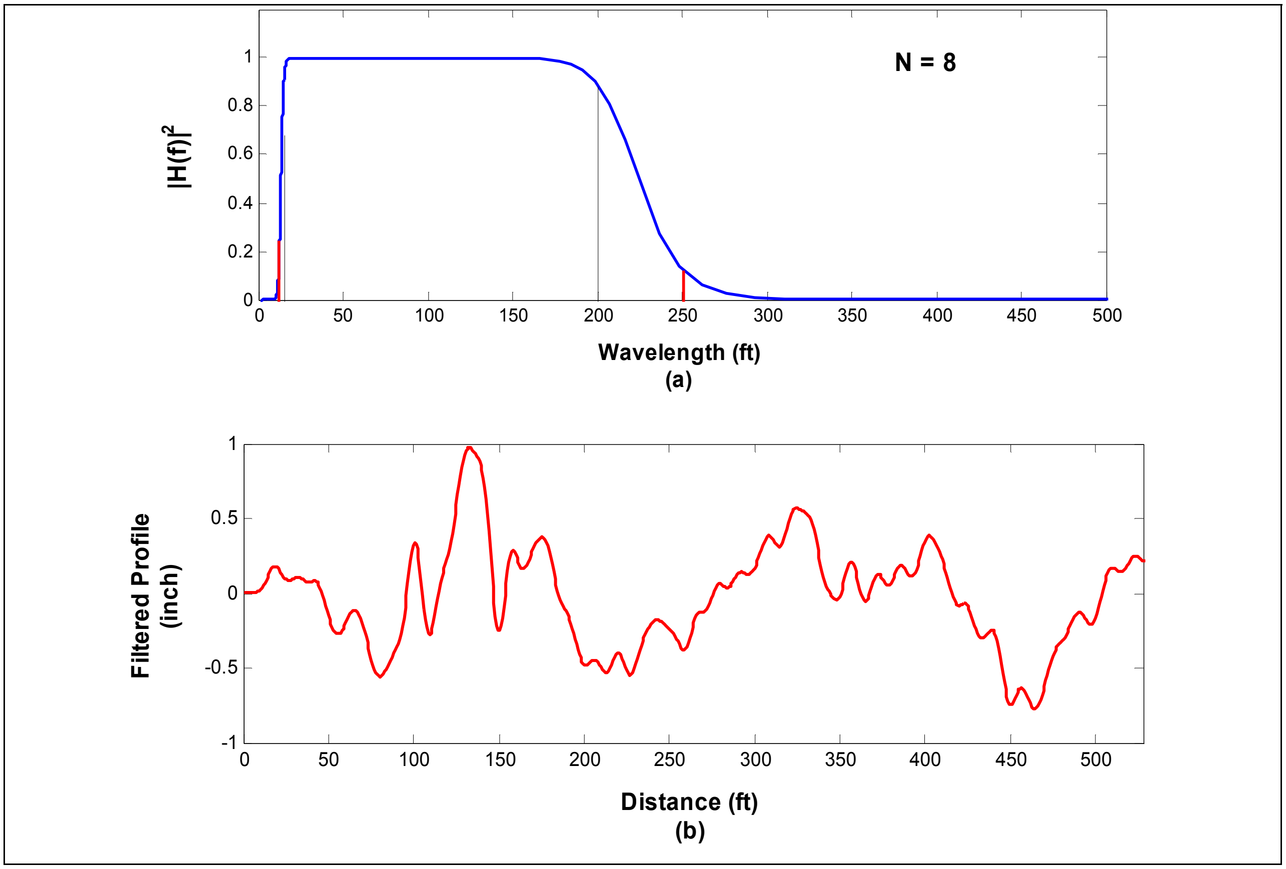


Figure 133. (a)Filter and (b) Filtered Profile.

Removing Vertical Curves using Spline Interpolation Technique

Geometry of the roadways (design vertical curves) accounts for a great portion of the lower frequency energy of the measured profile. Parabolic curves are used almost exclusively in connecting profile grade tangents. A typical "crest" highway vertical curve is shown in Figure 134. The exact shape of the vertical curves included in the measured profile depends on the position of the tested section with respect to the design vertical curve; it may be linear for some test sections and parabolic for others.

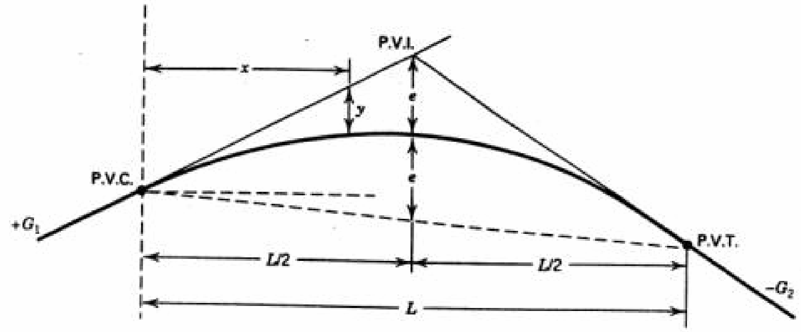


Figure 134. A typical "Crest" Highway Vertical Curve.

The part of the profile energy coming from the road geometry does not affect ride quality. Therefore, this should not be included in any indices used to describe ride quality. It is customary to filter the profile using a high-pass (with respect to frequency) Butterworth filter. This practice is inaccurate because it is not possible to set appropriate parameters (e.g. cut-off wavelengths, passband and stopband frequencies and attenuations) for the filter to eliminate the geometry trend. Furthermore, the higher frequency portion of the geometry curve spectrum (resulting from the edge effects) cannot be removed by this operation.

An intuitive alternative approach is proposed here for eliminating the effect of geometry. To estimate the geometry trend in this method, a number of reference points are marked throughout the profile. The reference points include the first and last elevation points. The middle points are then chosen as mid points of 50ft subsequent intervals along the profile. The distance of 50 ft is chosen because the distance between design reference points during the pavement construction is about 50 ft. At the next step, based on the chosen reference points, the geometry trend is estimated by a cubic Spline. The cubic Spline is very smooth and does not introduce artificial high frequency components in the profile. The final step involves the subtraction of the geometry trend from the profile. This procedure has been applied to a number of collected profiles and the selected results are shown in Figures 135, 136, and 137.

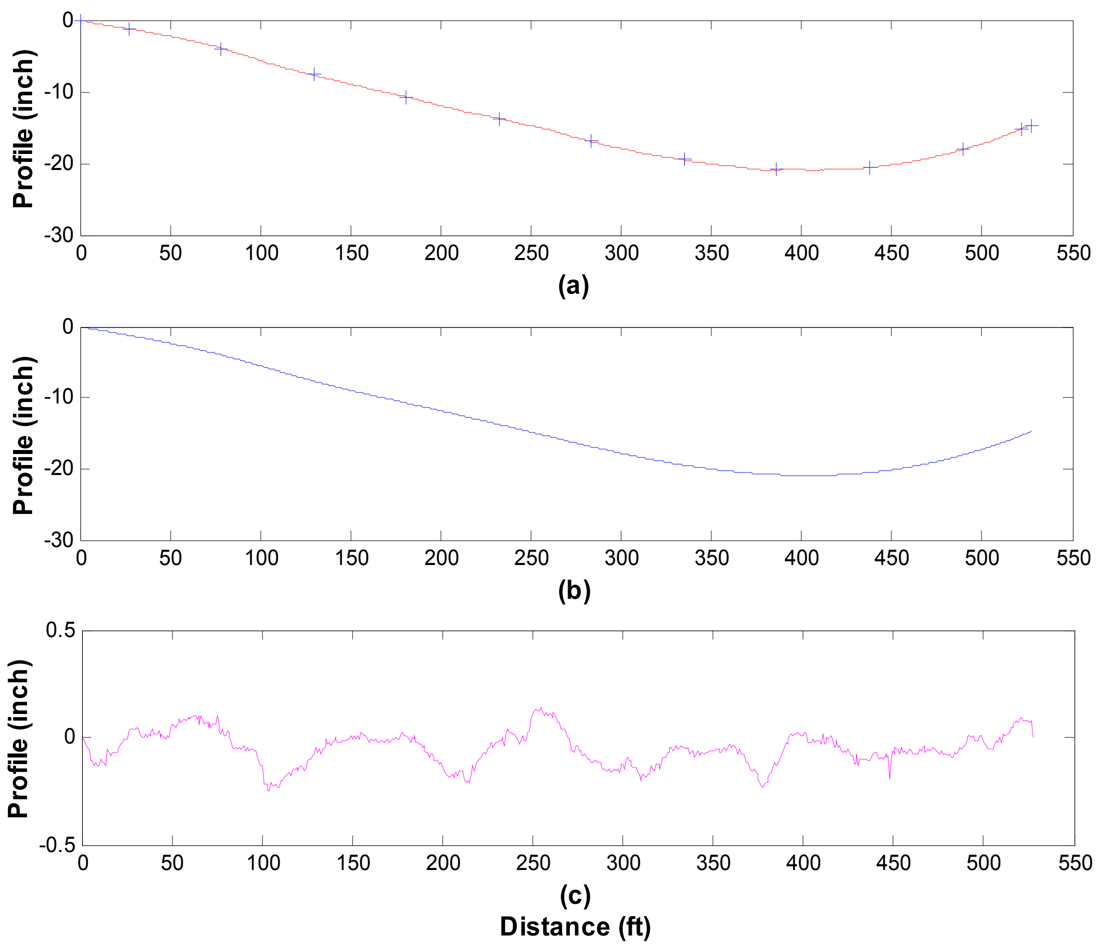


Figure 135. Rt55 S13 RWP: (a) Raw Profile and Reference Points, (b) Spline Geometry Trend and (c) Filtered Profile.

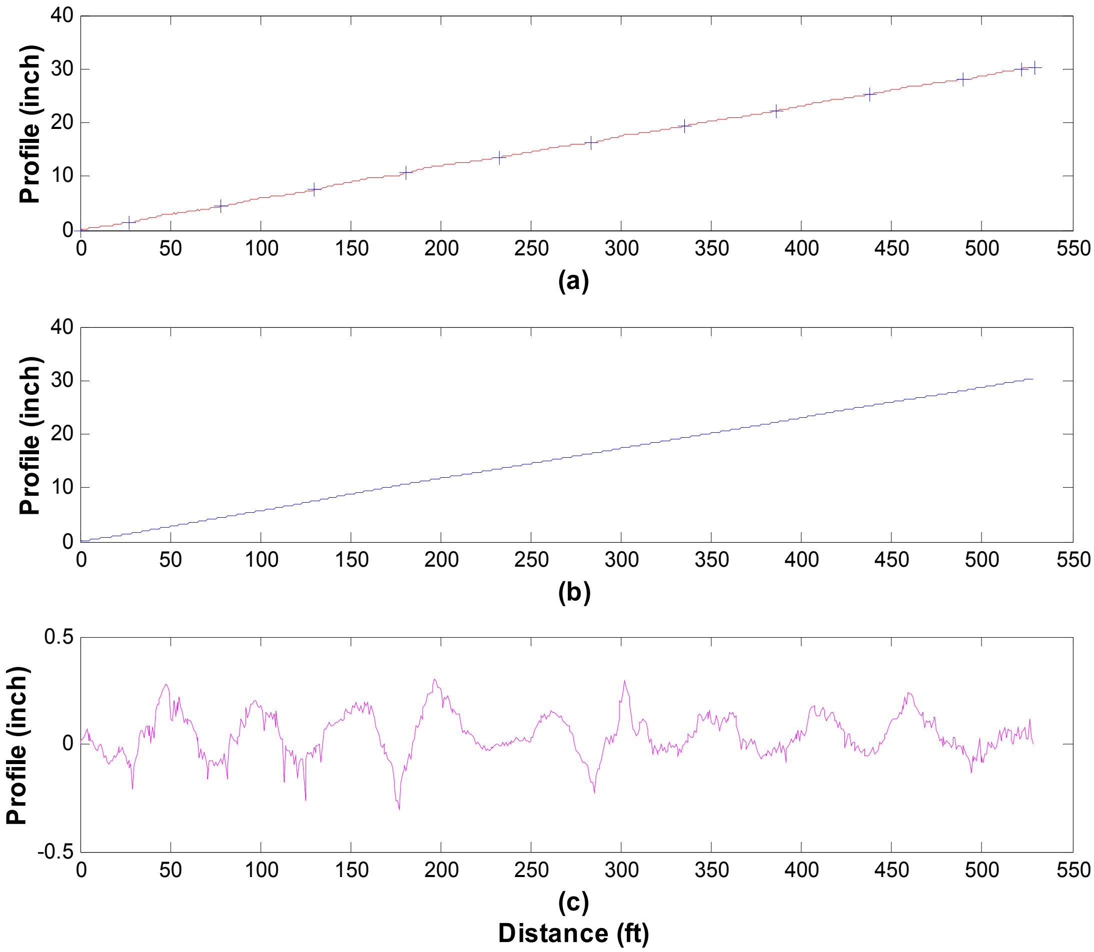


Figure 136. I195 S4 RWP: (a) Raw Profile and Reference Points, (b) Spline Geometry Trend and (c) Filtered Profile.

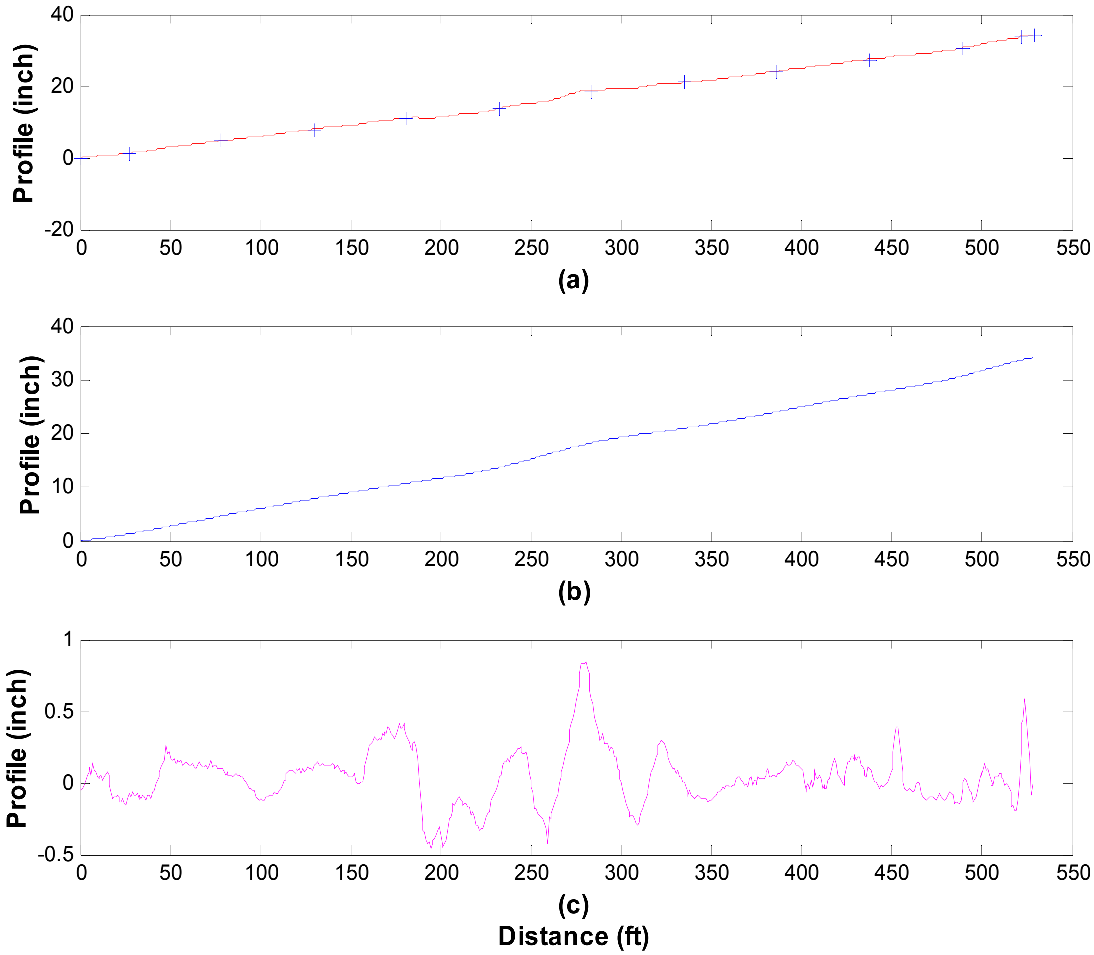


Figure 137. Rt18 S23 RWP: (a) Raw Profile and Reference Points, (b) Spline Geometry Trend and (c) Filtered Profile

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

In 1999, NJDOT initiated a study to evaluate the applicability of using automated profilers to replace RSEs used to implement the department smoothness specifications, Phase I study. Two categories of profilers were considered in the study, low-speed profilers, light-weight profilers (two devices), and high-speed profilers (three devices), in addition to two of NJDOT RSEs. The study concluded that the use of automated profilers was beneficial and have many positive impacts such as reduced inspection time, simultaneous provision of various roughness indices for improving pavement performance prediction models, and early detection of problems and subsequent remedial actions by contractors.

Phase I study however, also concluded that the accuracy of measurement varies significantly among profilers in terms of the recorded IRI values and testing speed in some cases may have some significant effect. This raised the issue of correlating various profilers against a common bench-mark. The study recommended that NJDOT select an automated profiler to replace the RSE as its official and standard smoothness measuring equipment, and correlation models developed to calibrate other profilers with the standard profiler. Additional recommendations were made to select an indicator that better represents ride smoothness as compared to using %DL or IRI.

In 2003, NJDOT initiated Phase II of the same study with the intention of addressing the issues raised in Phase I and to implement its recommendations. The objectives of Phase II study included selecting a pavement profiling device as the Standard Pavement Profiler (SPP) for NJDOT that will be used to calibrate/correlate other profilers with SPP and to develop the procedure required for this correlation.

The scope of Phase II study was limited to asphalt concrete pavements and included three roughness categories. Three test sections from each roughness category were selected. The right and left wheel path profiles of these test sections were measured using different profiling devices. Repeated runs (3 runs) at different speeds (3 speeds for the high-speed profilers) were also performed. To overcome the equipment problems of Phase I, two types of profiling devices were considered in Phase II, which are bench-mark (Rod and Level - R&L and ARRB Walking Profiler - WP) and high-speed profilers (NJDOT ARAN manufactured by Roadway Corporation, Dynatest 5051-MKIII-022 high-speed profilers and Stantec's RT3000 manufactured by the International Cybernetics Corporation - ICC).

The data collected in Phase II was analyzed using two approaches. In the first approach the traditional ride statistics (IRI, RN, PI and %DL) were used to address the variability among equipment (profile comparisons) equipment related issues (repeatability, effects of testing speed, filtering effects), manufacturers versus standard IRI computations (Proval and RoadRuf) and the impact of summary intervals.

In the second approach more detailed investigations were performed on the IRI algorithm and a new ride statistic was developed. Also, advanced profile analysis was performed to diagnose the profile characteristics that impact the rideability and user opinion.

Conclusions

Visual assessment of the profiles collected using R&L and WP indicates that the two devices provide very similar results. Therefore, WP will be selected as NJDOT SPP.

The profiles collected using high-speed profilers from some sections match reasonably well. However, in some cases, pronounced differences are observed between the profiles measured using the high-speed profilers and those measured using R&L/WP.

The repeatability of all devices was found to be in general good.

Speed can have a significant impact on the measured IRI, especially when it is reported at 52.8-ft intervals. This speed dependency significantly reduced when IRI is reported at 528-ft intervals.

HP filters do not have significant impact on R&L profiles. The amplitude of the RT3000 profiles decreases significantly when the high-pass cutoff length is reduced from 300 to 200 ft. Profiles after band filtering are also similar to those from the corresponding HP filtering.

The effect of filtering on the computed IRI varies from one device to another, with R&L being the least affected. The differences between the unfiltered IRI and those after band filtering are more pronounced than that between unfiltered IRI and those after high pass filtering.

The differences between the results from unfiltered and filtered profiles change depending on the roughness class. The trend of each equipment is not consistent and the differences can be significant. However, the 3-ft low pass filter and the band 3-300 filter have the most significant impact.

The IRI for the entire 528-ft section (except for RT3000 LP filtering) is less affected by filtering.

The difference between the IRI values calculated using the manufacturer IRI routine and those of RoadRuf and Proval could be significant.

IRI summary intervals may have significant impact on the reported IRI values. A length of 528-ft would be a suitable IRI summary interval for project level investigation.

RN analysis indicated that there is some variability among devices and this variability increases for rougher sections.

In general, RN was found to be not as sensitive to speed as in the case of IRI.

Filtering effect on RN was found to be similar to that on IRI.

Based on the data collected in this project, IRI and PI limits can be established to classify pavement sections in the three roughness classes with no overlaps. These limits could not have been established using RN or %DL.

Recommendations

A panel study was included in the proposal, however, due to budget constraints, none was performed during the execution of this project. The ride statistic developed by Rutgers could therefore not be validated with a measure of user or rider discomfort. It is recommended that a panel study be conducted in which both the driver and a passenger are instrumented to measure the quality or comfort of the ride. The instrumentation of driver and passenger will provide a means of correlating the riders' subjective opinion with an objective measure of the same ride and serve as a basis of validating the Rutgers ride statistics.

The instrumented panel study will involve the survey of several sections (at least three) in each roughness category. The instrumentation should be capable of measuring the individual motion of passengers.

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APPENDIX A:

laser sdp

The Laser SDP is a longitudinal profile measurement system that provides road profile data capture and real-time roughness index calculation using a combination of high-speed lasers and accelerometers.

The Laser SDP samples at 12.5 mm (1/2 in.) intervals and measures bumps as short as 100 mm (4 in) at variable speeds up to 100 km/h (60 mph) without loss of accuracy.

Two lasers, one over each wheel path, measure the vehicle's height above the road. Accelerometers monitor the vertical forces caused by surface deformities.

This profile data is used to calculate the low-speed roughness (riding comfort) of the road surface.

The International Roughness Index (IRI) and other indices are calculated in real-time, a feature which saves significant office data processing time and effort. Data is also recorded for further processing if desired.

Faulting of concrete pavements is also measured and reported using special fault detection software.

The Laser SDP meets US FHWA specifications for a Class II HPMS profiler which is the highest level for automated data collection.

The Laser SDP also meets or exceeds specifications for the ASTM Class I profiler which again is the highest performance level possible.

The excellent accuracy and repeatability of measurements made by the Laser SDP make this subsystem an excellent choice for project level applications such as monitoring project acceptance, enforcement of "end-result" specifications, etc.

Features and Applications

- Lasers and accelerometers measure roughness in each wheel path
- Integrated with Distance Measuring Instrument (DMI) for precise location information
- Develops a complete longitudinal profile
- Measures concrete joint faulting accurately
- Not affected by surface texture as are some ultrasonic sensors
- Samples surface at 12.5 mm (1/2 in.) intervals and reports bumps as short as 100 mm (4 in) or as long as 100 m (328 ft).
- Measures at variable highway speeds up to 100 km/h (60 mph) without loss of accuracy
- Calculates IRI or other specified indices in real-time
- Reports roughness for each wheel path or combined as required.
- Generates graphs and tabular reports
- Meets Class II FHWA profiler specifications
- Meets or exceeds ASTM (E950) Class I profiler specifications

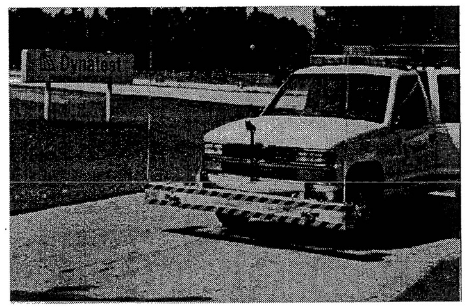
PRODUCTS

ROAD SURFACE PROFILER
5051 MARK II

The **Dynatest** **R**oad **S**urface **P**rofiler (RSP) is carefully designed to provide *the* automated, high quality pavement roughness and related measurements solution for engineers worldwide. The RSP performs continuous, highway-speed measurements of longitudinal and transverse profile, including real-time roughness (IRI), rut depth evaluation, GPS, and geometrics. This product line is available in several levels of sophistication, ranging from a 21 laser top-of-the-line version down to a single wheel path version for longitudinal profile/IRI evaluation only.

Advantages:

- **Guaranteed high accuracy according to rigorous standards**
- **High-speed measurements**
- **Dynatest worldwide support network**
- **Designed by pavement specialists**



Why a Dynatest Profiling System?

The **Dynatest** Mark II RSP was designed and developed by a team including specialists in pavement engineering who fully understand the requirements and needs of the professional pavement engineer and pavement manager, and who have had many years of experience in developing equipment tailored to meet these needs and requirements.

Additionally, **Dynatest** is committed to producing, and internationally marketing and supporting, industry-standard equipment of high durability, user-friendly design and rock-solid performance. **Dynatest** also provides knowledgeable pavement engineering expertise worldwide for the support of any Dynatest product.

The new Mark II can be installed in a variety of automobiles or vans used around the world. It is a "PC-card-based" test system. The processing electronics have been miniaturized and placed onto a Dynatest developed proprietary PC printed circuit board which mounts into an ISA slot in an IBM compatible portable PC. This results in a simplified system consisting of only two primary components:

- A transducer unit ("Rut Bar"), holding up to 21 laser sensors and from 1 to 3 accelerometers
- A ruggedized IBM compatible (laptop-like) PC with full-size expansion slot capability and dual high speed serial ports

Measuring principle:

The longitudinal profile measurement is based on the "South Dakota" method. An accelerometer is used to obtain vertical vehicle body accelerations, and a laser sensor is used for measuring the displacement between the vehicle body and the pavement. Road profile measurements are then obtained by summing the twice integrated acceleration measurements with the appropriate body-road displacements. IRI is calculated in accordance with World Bank Specifications. RSP longitudinal profile meets the Class 1 precision and bias specifications as defined by ASTM E-950 (USA).

Transverse profile and/or rut depth is measured by a minimum of 3 to a maximum of 21 lasers enclosed within the Rut Bar.

The RSP provides a product line designed to meet needs ranging from high quality measurements "on a budget", to the most sophisticated, rigorous research testing needs applicable to this type of equipment. Please contact Dynatest for complete specifications, pricing, and more detailed technical information.

Dynatest International rev. 971110a

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Florida	+ 1 904 964 3777 / psc@dynatest.com	Denmark	+ 45 44 53 33 55 / denmark@dynatest.com
S. Africa	+ 27 (0)11 807 0660 / rsa@dynatest.com	Brazil	+ 55 (0)11 287 2226 / brazil@dynatest.com
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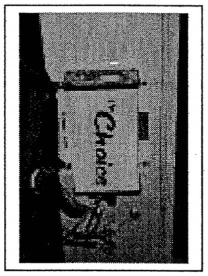
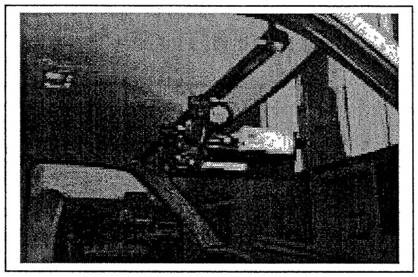
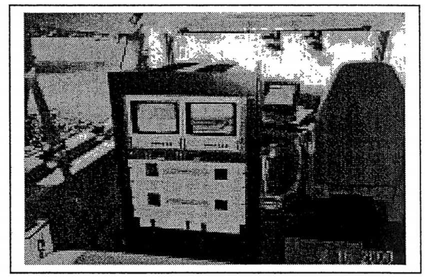


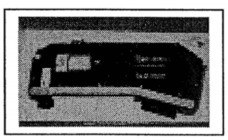
Trimble DGPS



Pavement and ROW Video - Mandli

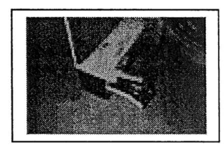


Video Recording Station - Mandli

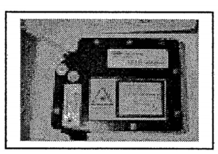


Angled Rangefinder

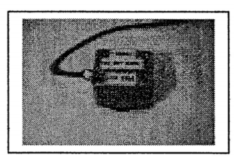
Dynatest RSP 5051 MKII L3.2



Angled Rangefinder



Vertical Laser Rangefinder



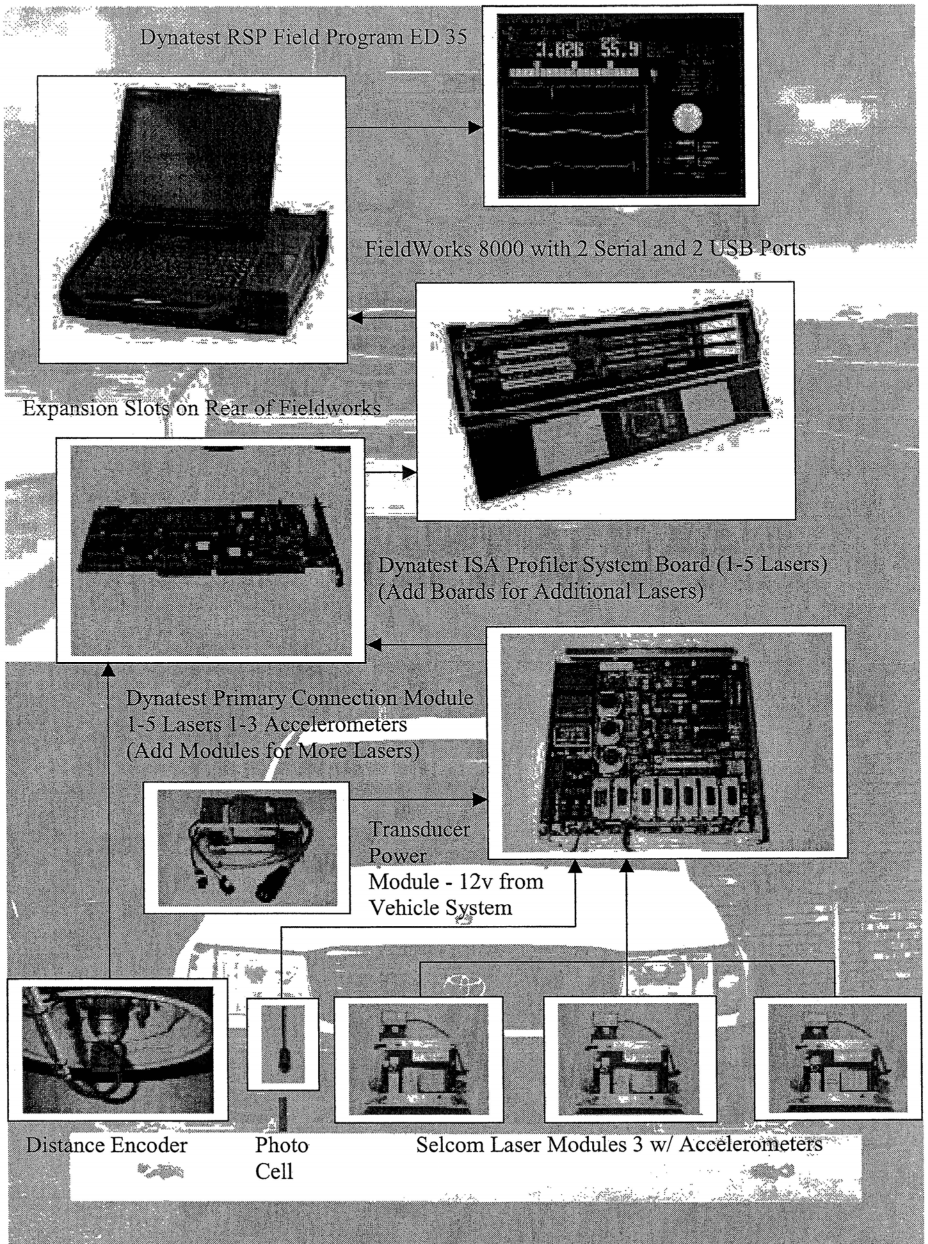
Maximum of 3 Accelerometers

Gyroscope Option – Grade, Crossfall and Curvature

<u>Dynatest Road Surface Profiler System</u>

- Modular & Upgradeable
- Easy to Operate and Maintain
- Real Time Indices (IRI, Ride, Rut, Crossfall, Grade, Turn Rate, Faulting & DGPS)
- 1 to 21 Laser Rangefinders
- 1 to 3 Accelerometers
- Differential Global Positioning Option
- Gyroscope Capable
- Video Options Available

Dynatest®



DYNATEST RSP MODEL 5051 MkII VERSION L3.3 – MODULAR SYSTEM

RSP/5051/**L2.2**

THE DYNATEST MODEL 5051 MARK II ROAD SURFACE PROFILER

TEST SYSTEM SPECIFICATIONS

GENERAL:

The Road Surface Profiler (RSP) Test System (hereafter called the System) shall be a new, currently advertised production model. The manufacturer of the System shall have a full parts inventory and a well-established record of equipment support. The System shall include all standard equipment advertised, whether or not specifically called for herein, including the manufacturer's standard warranty. The System shall consist of at least one accelerometer and laser optical distance measurement device (hereafter called the Transducer), mounting system, e.g., Transducer Beam, plus an appropriately matched electronic package for registration of the Transducer signals, including a hardware/software package for automatic recording and preliminary data processing in the field. The System shall be mountable in a reasonably sized vehicle, such as e.g., minivan or full size van.

The System shall be able to measure, display, store (on computer hard disk) and calculate longitudinal road profile and roughness data in wheel paths, plus vehicle position (stationing) and speed as described in the following sections.

The System shall meet the requirements for a "Class 1" profilometric device as outlined in ASTM E 950-94, "*Standard Test Method for Measuring the Longitudinal Profile of Traveled Surfaces With An Accelerometer Established Inertial Profiling Reference*" and World Bank Technical Paper #46 "*Guidelines for Conducting and Calibrating Road Roughness Measurements*".

The System shall be designed as a modular, upgradeable product such that future upgrades can be performed without significant modification to the Transducers and electronics hardware or to the software package. Upgrades are defined as the addition of accelerometer/laser combinations to allow for profile measurements in more than one wheelpath (up to 3 total) or the addition of lasers (up to 21 total) to allow for measurement of transverse profile. Additionally, an IMS (Inertial Motion Sensor, for measurement of crossfall, grade and degree of curvature) and a Differential Global Positioning System (DGPS) can be added.

DETAILED:

1. General Operational Requirements

1.1 The System shall be operable by one person (i.e., the vehicle driver).

1.2 The System shall be operable at highway speeds up to 115 km/h (70 mph), to allow safe operation in on-going traffic in the field.

1.3 The System shall be designed and constructed so as to operate satisfactorily in the rugged environment of a test vehicle.

1.4 The System shall operate satisfactorily under all typical, dry weather conditions within the temperature ranges specified below.

1.5 The System shall be able to operate in an ambient temperature range of 0 C to + 40 C (+32 F to +105 F) outside the vehicle, and +5 C to + 40 C (+40 F to +105 F) inside the vehicle, provided that no condensing moisture occurs.

1.6 The System power requirements shall be 12 VDC nominal (10.5 to 14.5 VDC) only, provided from the electrical system of the towing vehicle. A solid-state inverter shall be provided for computer (and optionally printer) powering.

2. Transducer Beam

2.1 The L2.2 Transducer Beam shall be a mechanically rugged beam, made from corrosion resistant material, such as aluminum, holding two (optionally 21) laser displacement sensors and two (optionally three 3) accelerometers.

2.2 The Transducers shall be in the form of easily removable/ exchangeable modules.

2.3 Two of the laser sensor modules shall be placed over the right and left wheel paths, at a lateral distance of 700 to 914 mm (27.5 to 36.0 inches) from the (longitudinal) center line of the vehicle, for the purpose of providing displacement data needed for the computation of longitudinal profiles and/or IRIs (International Roughness Indexes) in both wheel paths. Refer to 2.1 above.

2.4 The Transducer Beam shall provide the capability to mount two or optionally three high precision accelerometers so as to accurately monitor the vertical movement of the two wheel path laser sensors (and optionally the center laser) respectfully.

2.5 The accelerometers shall be easily removable for calibration or replacement.

2.6 The Transducer Beam shall provide necessary protection of the laser sensor modules, the accelerometers and all cables/plug connections against normal, non-frosty weather conditions, such as rain (see also 1.5 and 6.4).

2.7 The nominal, vertical clearance (distance) between the bottom of the Transducer Beam and the pavement surface shall be not less than 280 mm (11 inches) in the transport as well as in the measuring mode.

3. Transducers

3.1 The vertical laser displacement sensors shall have a measuring range of at least 200 mm (7-7/8 inches), i.e. +/- 100 mm (+/- 3-15/16 inches) from the mid-range position (which is the nominal measuring position, i.e., the long-term, average "zero" position).

3.2 The vertical displacement measuring resolution of the laser sensors shall be better than or equal to 0.05mm (+/- 2 mil).

3.3 The laser sensors shall be able to produce at least sixteen thousand (16,000) displacement measurements per second.

3.4 The vertical accelerometers shall have a measuring range of +/- 2.5 g min. in a frequency range from zero (0) Hz to 300 Hz min. (-3 dB). Below 50 Hz, the measurement accuracy shall be within +/- 1% of the measured value or +/- 0.003 g max., whichever is the greater.

3.5 A digital encoder, mechanically linked to one of the vehicle wheels, shall be provided for suitable digital distance/speed information to the signal processing electronics.

4. Signal Processing Hardware/Software

4.1 A PC-card-based electronic microprocessor circuit board and remote distribution and power panel, in the following called a System Processor, shall be provided with the System. The System Processor shall use up-to-date, field proven technology.

4.2 The System Processor shall provide all necessary power for the transducers (laser sensors, accelerometers and distance/speed encoder).

4.3 The System Processor shall provide signal conditioning and sampling hardware for all transducers.

4.4 The System Processor shall sample the signals from the wheel path laser sensors and accelerometers at a rate of not less than 16 kHz (corresponding to less than 2 mm (0.08") of travel at any speed up to 115 km/h (70 mph)).

4.5 Based on the so-called South Dakota method, the System Processor shall be able to compute - in real time - the longitudinal profiles of both wheel paths from the sampled signals of the laser sensors and accelerometers. The longitudinal profile-reporting interval shall be selectable to approx. 25 mm (1 inch) or more.

4.6 The System Processor shall optionally be able to provide *real-time* computation of IRIs (International Roughness Indexes) in accordance with World Bank guidelines. This optional IRI data shall be displayed on the PC screen during testing.

5. Data Recording System

5.1 The system shall include a portable microcomputer (PC), such as e.g., a Pentium based notebook PC with DOS 6.0 or higher, 16 MB RAM min., a hard disk of 810 MB min., a 3-1/2 inch/1.44 MB floppy disc drive and a color active matrix display. The PC will allow direct installation of the System Processor (PC-Card Based) board.

5.2 A so-called Field Program (including necessary parameter files and setup programs) shall be supplied, which shall be capable of - when installed into the PC - conducting full control of the testing operations from the PC keyboard.

5.3 The PC with Field Program shall be capable of communicating with the System Processor via the PC's ISA bus interface and shall transfer all necessary setup data to the System Processor at System start-up, and shall during testing with the System receive all processed measuring data from the System Processor for further processing, display on the PC Screen and storage on the PC hard disk.

5.4 The Field Program shall allow the System operator to enter operational parameters and other information, such as:

- Beginning station of the road section to be tested
- Increasing or decreasing stationing during the test run
- Longitudinal profile filter length
- IRI reporting interval (optional)
- Data file names

5.5 It shall be possible to select the (optional) IRI reporting interval in the min. range of 10m (or 30 ft) to 1 km (or 1 mile).

5.6 It shall be possible to select a longitudinal profile filter length of up to at least 100 m (330 ft.).

5.7 The System shall include post-processing software for computation of IRIs from longitudinal profile data. This software shall be fully compatible with the longitudinal profile data files recorded during field-testing, and the output files generated by this software shall be in ASCII code.

6. Performance Accuracy and Calibration

6.1 The System shall have a repeatability error on IRI data (whether measured in real-time or post processed) of typ. less than 5% (coefficient of variation) OR 0.1 m/km (6in/mi.) (sample standard deviation) whichever is the greater, for 6 repeated runs (selected from 10 runs) at test sections of a length of 160 m (0.1 mile) min.

6.2 The distance displayed and stored with the test data shall be accurate to within +/- 0.05% or 0.8 m (2.6 ft.) of true distance, whichever is the greater, for a 5280 ft. (1610 m.) test section on condition that the measurement is initiated exactly at the pre-entered beginning station and provided the effective radius of the wheel/tire remains constant.

6.3 Equipment, procedures and software necessary to perform (static) calibration of the laser sensors and accelerometers and field calibration of distance measurement shall be included with the system.

6.4 Equipment accuracy shall remain stable for all types of (dry) pavements, and calibration shall not be required on a frequent basis.

7. Documentation

7.1 Two (2) complete sets of User Manuals shall be provided by the manufacturer which include a set of drawings and diagrams, except for the chosen computer and any proprietary electronics, for all equipment so that the purchaser will be able to operate and maintain the System properly.

7.2 All proprietary electronic modules shall be available on short notice from the manufacturer as replacement parts, and they shall be readily interchangeable.

7.3 The System described in the foregoing Sections shall conform in all respects to the Specifications and Stipulations brought forth therein.

8. Warranty

8.1 With the exception of the recording/playback microcomputer instrument specified in Section 5, the System shall be expressly warranted to be free from defects in materials and workmanship for a period of one (1) year from the date of acceptance of delivery by the purchaser. This express warranty shall be limited to the prompt repair and replacement of parts and the necessary labor and services required to repair the System, with the exception of the recording/playback microcomputer instrument specified in Section 5. In the event large or heavy components of the System, with the exception of the recording/playback microcomputer instrument described in Section 5, prove to be defective during the period covered by this express warranty, the producers may, at their option, make the necessary repairs at one of its places of business or at the place where the System is located.

This express warranty shall be extended to purchaser at no additional cost, except that (a) the purchaser shall be liable for all shipping costs and expenses incurred in delivering any small parts of the System to the manufacturer, and (b) in the event the manufacturer chooses to replace or repair any defective large or heavy components of the System at one of its places of business during the period covered by this express warranty, the manufacturer shall defray all shipping costs and expenses incurred in delivering both the defective components to the manufacturer and the repaired or replaced components back to purchaser. The recording/playback microcomputer instrument specified in Section 5 shall not be covered by this express warranty and shall be covered by the standard warranty provided by the manufacturer of the microcomputer.

This express warranty, in addition to its general repair and replacement remedy, provides an option to return the equipment for the purchase price if it generally fails to meet the performance specifications listed in Section 6 (above). The return option is applicable only if within 12 months of delivery, the equipment, under normal, intended use and with recommended maintenance, fails in a significant way to perform according to the performance specifications in Section 6. To exercise the return option, the purchaser must clearly demonstrate to the producer a general performance deficiency with respect to the measurement accuracy as defined by Section 6 of these equipment specifications.

8.2 The express warranty set forth in Section 8 is the exclusive and only warranty extended by the manufacturer to the purchaser. The manufacturer makes no warranty of merchantability with respect to the system purchased and makes no warranty that the system purchased is fit for any particular purpose. There are no warranties, which extend beyond the description on the face hereof.

8.3 The express warranty set forth in Section 8 shall not apply to any defects in the System caused by the negligence or misuse by purchaser or its agents, employees, or representatives in the operation of the System.

8.4 In the event of a breach or repudiation by the manufacturer of the contract for the sale of the System, the purchaser shall not be entitled to recover any incidental or consequential damages as defined in the California Commercial Code.

8.5 The System described in the foregoing Sections shall conform in all respects to the Specifications and Stipulations brought forth therein.

International Cybernetics Corporation

Road Profiler
Technical Description

The ICC Road Profiler is considered a South Dakota style road profiler. The technology used to make the height measurements with ultrasonics and the filtering algorithms used to do the accelerometer vertical positioning were developed by the South Dakota Department of Transportation. ICC has added the use of lasers for height measurements, additional height sensors, an additional accelerometer and other features to enhance the original road profiler.

International Cybernetics Corporation (ICC)
Road Profiler
PROFILE MEASUREMENT AND ANALYSIS

The ICC Road Profiler is an "inertial" profile measurement device -- that is, it utilizes an accelerometer to establish a reference plane from which the profile is measured. Figure 1 illustrates the principle of measurement.

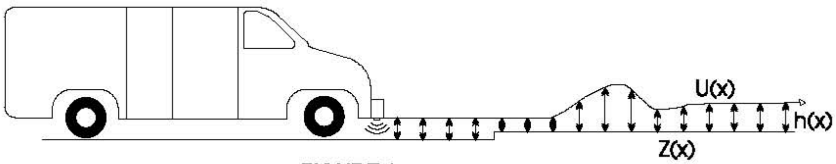


FIGURE 1

As the test vehicle moves in the horizontal direction x, it encounters the vertical roadway profile z(x). In response to the profile, the vehicle body moves vertically, as indicated by the curved line u(x). At every point along the vehicle's path, the difference between the road profile z(x) and the vehicle's vertical position u(x) is h(x), the distance between the vehicle body and the pavement surface. Stated mathematically,

$$h(x) = u(x) - z(x)$$

or equivalently,

$$z(x) = u(x) - h(x)$$

The significance of this Equation is that if u(x) and h(x) can be measured, the road profile z(x) can be computed. This is true, regardless of the vehicle's suspension characteristics. For any vehicle response, u(x) and h(x) vary together, such that their difference equals the profile z(x).

The Road Profiler determines the vehicle's vertical position u(x) by numerically integrating a measured vertical acceleration signal. An ultrasonic or laser displacement sensor measures the height distance h(x) between the vehicle body and the pavement surface. The road profile z(x) is computed as the numerical difference between u(x) and h(x).

Conceptually, the process can be divided into six operations. These are : 1) measurement of the vertical displacement of the vehicle as a function of time; 2) measurement of the horizontal distance the vehicle has traveled; 3) measurement of the vehicle's height above the pavement surface at equally spaced intervals of highway distance; 4) synchronized subtraction of the vehicle displacement and height measurements to compute the highway profile; 5) storage of the data points; and 6) reconstruction of the filtered profile from the stored profile for purposes of inspection, analysis, or calculating information based on profile.

The first five operations are performed in real time, as the test vehicle drives down the highway at normal traffic speeds. Profile reconstruction and analysis is performed after the data is returned from the field or in the vehicle after data collection is complete.

Vehicle Displacement Measurement

Direct measurement of the test vehicle's vertical displacement through space is impractical, but it is possible to measure the vehicles vertical acceleration as a function of time and then integrate the acceleration to generate the displacement record.

A linear servo accelerometer measures the vehicle's vertical acceleration at each wheel path. The profiler calibration determines the bias for one "g" to eliminate the acceleration due to earth's gravity from the signal output. Its range of plus or minus two "g" and frequency response of 0-11OHz are adequate to measure significant vehicle motions which fall in the range of plus or minus one "g" at 0-5Hz.

In addition to meaningful accelerations, the accelerometer signal contains high frequency components corresponding to extraneous vehicle body vibrations. A linear phase lowpass filter is used to attenuate these components. Sampling theory dictates that the filter eliminates frequencies higher than the Nyquist frequency, which is one-half the 125 Hz sampling frequency. In practice, elimination of frequencies higher than one-fourth the sampling frequency is desirable. The filter passes frequencies of interest with as little attenuation as possible.

A 20Hz eight pole lowpass filter for each accelerometer is mounted on a circuit board located within the Road Profiler computer. The board also carries an operational amplifier which multiplies the acceleration signal by a factor of two to increase the signal level to five volts per "g", and a bipolar fifteen volt power supply module which provides power to the accelerometer, filter module, and operational amplifier.

Below 2Hz, where the most significant vehicle accelerations occur, the signal loss is less than 0.7%. At 4Hz, the loss is approximately 2.7%. At 20Hz, the signal is attenuated by 50%, and at the Nyquist frequency at 62.5Hz, the signal is attenuated by 99.95%. The delay introduced by the filter is a nearly 25.3milliseconds in the frequency range of 0-40Hz. delay decreases to 12.3 milliseconds at 62.5Hz.

After the acceleration signal is filtered, it is converted into numbers which may be manipulated by the computer. A multi-channel 12-bit analog to digital converter installed in the computer digitizes the signal in each wheel path at 8 millisecond intervals, converting signal levels between -10 volts and +10 volts (corresponding to accelerations of minus one "g" and plus one "g") into integers between -2048 and +2048. The resolution of the acceleration signal is one "g" divided by 2048, or 0.01571 ft/sec. .The a/d converter's stated accuracy is plus or minus 0.025% of full scale reading, or approximately one half its resolution.

Acceleration sampling must occur precisely at timed intervals to insure accuracy in the subsequent integration. Measurements are initiated by a crystal controlled clock programmed to generate interrupts at intervals of 4.0 milliseconds. The clock is equipped with an error flag to indicate whether interrupts are being serviced by software as quickly as they are being generated. Profile measurement software monitors the flag and verifies the acceleration changes are occurring and will warn the operator if any errors were detected. Tests have shown that the hardware and software are capable of sustaining the 125Hz sampling rate for each wheel path under any conceivable operating conditions.

Each digitized acceleration signal is integrated twice to yield a record of vehicle vertical displacement. The Road Profiler integrates numerically rather than with electronic circuit to avoid problems of integrator saturation.

The problem of offset errors is inherent to both analog and numerical integration. When an acceleration signal composed of a true time-varying acceleration a(t) plus some constant

a_{off} is integrated twice, the computed displacement u* (t) consists of the true displacement u(t), one error term due to the initial (unknown) vertical velocity v_o , and another error term proportional to the square of time t. That is,

$$u^*(t) = u(t) + v_o t + \frac{1}{2} a_{off} t^2$$

It is evident that for small offsets, the terms involving t^2 predominates as time increases. For a profile ten miles in length, t exceeds one half million seconds squared assuming a test speed of 50 mph. Even if the offset is only one thousandth of a "g", the displacement error is approximately 8300 feet, over 1.5 miles in elevation! Although the error term is involving velocity, v is proportional to time and grows more slowly, it too can overwhelm the true displacement. Fortunately, because both error terms vary slowly, they can be controlled by removing extremely low frequencies from the integrated displacement signal.

A numerical process, a type of digital filter, simultaneously integrates and filters the acceleration signal as it is measured. The filter can be described by its transfer function which specifies the ratio of output to input within the frequency range of interest. The composite transfer function can be expressed as the product of an integration transfer function I(f) and a highpass filtering transfer function H(f), where f is the frequency of the signal:

F (f) = I (f) * H (f)

The ideal double integrator transfer function

$$D(f) = -\left[\frac{1}{2(\pi f)}\right]^2$$

is numerically approximated by the transfer function

$$I(f) = -\left[\frac{h}{2\sin(\pi f h)}\right]^2$$

The quality of this approximation depends upon the signal frequency and the sampling interval h. The ratio of actual to ideal integration is given by the relationship

$$R(f) = \frac{I(f)}{D(f)} = \left[\frac{\pi f h}{\sin(\pi \mathrm{fh})}\right]^2$$

The ratio is exactly one when the frequency is zero, but reaches a maximum value of 2.47 at the Nyquist frequency. At 5Hz, below which vertical acceleration signals of interest lie, the approximation over estimates the displacement magnitude by 0.5%. It is important to note that while the integration increasingly overestimates at higher frequency, the lowpass antialiasing filter so strongly attenuates with increasing frequency that no net overestimation occurs.

The highpass filtering transfer function is

$$H(f) = \frac{1}{\left[1 + \frac{\cot^2(\pi f h)}{\cot^2(\pi f_0 h)}\right]}$$

which has complete attenuation at zero frequency, 50% attenuation at the cutoff frequency f (0.01Hz for the Road Profiler) and no attenuation at the Nyquist frequency. Because the transfer function is only second order, the filter does not exhibit sharp rolloff. Its performance is sufficient, however, to limit the growth of integration errors.

The complete filter transfer function F (f), the product of I (f) and H (f), is accomplished as a second order recursive digital filter of the form

$$u_n = Au_{n-2} + Bu_{n-1} + Ch^2a_{n-2}$$

where the constants A, B, and C are determined analytically from the sampling interval h and the cutoff frequency f . That is, the displacement at time t is given as a linear combination of the two previously computed displacements and the acceleration measured two sampling intervals previously.

The integration algorithm introduces a signal display of two sampling intervals at all frequencies, so that the displacement computed at time t actually corresponds to the vehicle displacement at time t-2h. In addition, the highpass filtering introduces delay which increases rapidly as frequency decreases. Longwave vehicle displacement components are shifted significantly.

Assuming a vehicle speed of 55 mph, the "gain ratio" -- that is, the ratio of computed displacement--varies within plus or minus two percent over the frequency range of 8Hz to 0.08Hz, corresponding to wavelengths of 10 feet to 1000 feet. At frequencies above 1Hz, the signal delay is nearly constant and equal to a distance equivalent to two sampling intervals, or about 1.3 feet. At lower frequencies, the signal delay increases significantly; at a frequency of 0.0114Hz, corresponding to the wavelength of 7000 ft, the signal delay exceeds 1000 feet.

The sampling frequency, highpass frequency, and vehicle speed normally used by the Road Profiler, the highpass integration accurately estimates the amplitude of vehicle motion at wavelengths up to 1000 feet, but not without phase distortion and delay at longer wavelengths. Because the vertical motion of the vehicle is restricted to frequencies below 5Hz, the integrations overestimation at higher frequencies is insignificant.

Because the integration and filtering are time-based rather than distance-based, these wavelengths and distances depend on vehicle speed.

Delays that appear in the data are removed by filtering the data down to wavelengths of 300 feet or less.

Vehicle Height Measurements

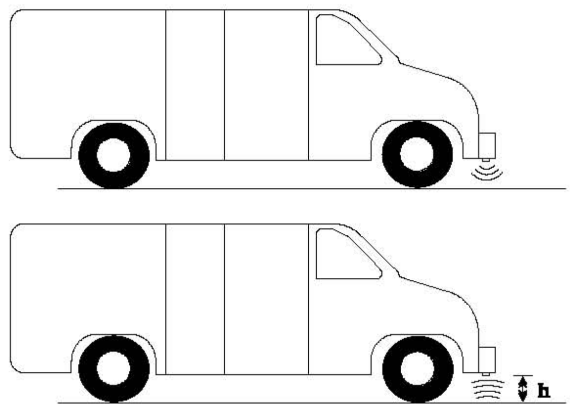
The distance between the accelerometer and the pavement surface in each wheel path is measured by an ultrasonic or laser ranging device mounted on the instrumentation bumper.

The ultrasonic sensor uses an instrumentation quality version of the electrostatic transducer used on auto focusing Polaroid cameras.

Its principle of operation is relatively simple; a short burst of 50KHz sound waves is generated by the transducer, travels downward to the pavement surface, and is reflected back to the same transducer (FIGURE 2). The elapsed time t between sound generation and echo detection is proportional to the distance h between the transducer and the pavement surface, according to the relation

$$h= ct/2$$

where "c" is the velocity of sound in air, approximately 1125 feet per second. At the transducer's equilibrium position, approximately one foot above the pavement surface, the lapsed time is about 1.8 milliseconds. To prevent interference resulting from multiple echoes, measurements must be performed at time intervals exceeding ten milliseconds.



$$h= t*c/2$$

FIGURE 2: Ultrasonic Ranging Principle

Ultrasound generation, detection, and timing is provided by sensor electronics in the bumper. The sensor is controlled by an interface board installed in the computer. When the computer determines that the vehicle has traveled the specified sampling distance, software commands the interface and sensor to generate the ultrasound transmission. When the echo is detected, the system provides a count representing the elapsed time interval accurate to one microsound.

The transducer's "footprint" on the pavement surface is approximately two inches in diameter. Since timing stops upon receipt of the earliest echo, any large object (of cross section area exceeding one square inch or so) which protrudes above the surrounding surface may be detected instead of the background surface.

Coarse surface texture can affect the measurement in two ways. First, there is inherent uncertainty in defining the distance between transducer and coarse pavements--which surface elevation is the correct one? Secondly, randomly oriented aggregate surfaces presented by coarse pavements may scatter the ultrasound or cause destructive interference resulting in late echo detection. This problem occurs mainly on extremely coarse--5/8 inch or greater aggregate size--chip seals. Smaller chips, cracks, open graded asphalt mixes, and tined concrete will cause slight increases in signal variance. Although timing accuracy allows measurement resolution of 0.005 feet, pavement surface effects limit accuracy to 0.002 feet on smooth pavement surfaces and 0.006 feet on very coarse surfaces.

During the time between signal transmission and echo detection, a vehicle traveling 55 mph moves forward approximately 1.7 inches, a distance approximately equal to the transducer's diameter. No correction is made to compensate for the oblique sound path because correction would be speed dependent and precise identification of the transmission, reflection and reception surfaces is impossible.

The system provides a data entry parameter for ambient temperature to provide some compensation to correct the distance measurement for effects of air temperature on sound velocity. Each 10 degrees F change in ambient temperature effects the measurements about 1%. However, air temperatures may have a temperature gradient and vary as much as 30% with height above heated pavement surfaces. Accurate temperature compensation for this would be more difficult than the expected measurement improvement would justify.

Because vehicle height measurements are taken at specified intervals, profile features shorter than twice that interval are inadequately sampled. As a result, short features are incorrectly interpreted as features longer than twice the sample interval. This phenomenon--termed "aliasing"--is most severe when the profile has a high short wavelength content. In general, the computed International Roughness Index for such profiles will be higher than it should be. Aliasing can only be eliminated by decreasing the sampling interval. Because the ultrasonic sensors' sampling frequency is limited to 100Hz, the only way to shorten the interval is to decrease vehicle speed. This allows sample intervals of approximately 1 foot yielding wavelengths of 2 foot and higher. The system allows the operator to select a lower interval of approximately 9" or 6" and indicates to what speed the vehicle must be kept to not encounter errors due to previous echoes.

The laser sensor used in the wheelpath positions is a Selcom infrared laser with a 1 to 2 mm footprint on the pavement. The laser samples at 32,000 or 16,000 times per second. This provides a sample every 1mm at 60 miles per hour. The samples are averaged and stored at a distance sensor interval selectable by the operator. The normal network and project level selectable intervals are approximately 3",6",9",12", etc. Smaller intervals can be supplied for research purposes. The laser height data allows wavelengths down to one-half foot to be sampled. When laser and ultrasonic data are used together they are synchronized on distance sensor intervals for rut depth measurements.

Several lasers are available. The normal profile laser has a static resolution of 0.002 inches and a static inaccuracy of the laser measurement of plus or minus 0.010 inches. The measurement range is $\pm$ 3.9 inches about its center point. The measurements are not affected by temperature in the operational range. Coarse surface textures will cause more variation in the data than smooth surfaces. However, the high sampling rate yields height accuracy's under .010 inches on many open grade surfaces while speeds of 40 to 50 MPH are used. A second laser is available for profiling on research projects which has a 0.001 resolution, plus and minus 0.005 inaccuracy, and a plus and minus 2.5 inch measurement range.

The software monitors the height measurements stored to verify that they are in an operator selectable range. If errors are detected a warning message is sent to the operator and error codes are stored with the individual height sensor readings. The post processing software will replace bad readings with the last good reading while producing a profile, determining rut depth or calculating a roughness index.

Synchronized Profile Computation

Due to the electronics and software used, the times at which vehicle position and vehicle height are measured generally do not match. The software must merge the two records and compute the profile as their difference.

z(x) = u(t) - h(x)

The situation is complicated by delays--25 milliseconds in the analog lowpass filter and 16 milliseconds in the integration--which are introduced into the vehicle displacement record. These delays prevent the vehicle position from being available until approximately 40 milliseconds after the vehicle height measurement is completed.

The software overcomes this difficulty by saving vehicle height measurements, along with their measurement times, in a buffer area. When vehicle displacement is computed, its time--minus the known delay time--is compared to the time of the older stored height measurement. When the times match within one half integration period, the profile height sensor value and integrated accelerometer data are stored for the distance interval. The error introduced by the maximum mismatch of 4 milliseconds is negligible because of the low frequency content of the vehicle displacement record. The data is combined into profile data and rut depth data in post processing. When lasers are provided the intergration period is decreased and the maximum mismatch is lowered to 1 millisecond.

Data Storage

The matched profile data is stored in memory during the run and saved on one of the computer's disks after data collection is complete. The data to determine profiles and rut depth is stored in one file. In addition, optional event data like comments and roadway features may be entered by the operator and these are stored in a second file. A third optional file may contain vehicle speed data which can be used to indicate where speeds were too slow to rate roughness in post processing. Other optional sensor data is stored in separate files and all of these files are linked together by a pulse count from the distance sensor allowing data between files to be linked to within approximately 0.25 feet.

Profile Reconstruction

After the profile data is recorded on diskette, it may be plotted or further analyzed for roughness ratings. For both processes, it is desirable to filter the profile further to remove long wavelength components. Plotting and rating programs utilize a digital recursive filter with the transfer function.

$$H(w) = \frac{1}{\left[1 + \frac{\cot^2(\pi)\frac{h}{w}}{\cot^2(\pi)\frac{h}{w_0}}\right]}$$

This filter is a spatial lowpass filter, where w denotes the wavelength, w_0 is the desired cutoff wavelength, and h is the data interval. Its formulation, similar to that of the highpass filter employed in the double integration, is of the form

$$P_n = Az_n + Bz_{n-1} + Cz_{n-2} + DP_{n-1} + EP_{n-2}$$

That is, the filtered profile p is computed recursively as a linear combination of the unfiltered profile z at the present location and the filtered and unfiltered profile two data intervals previous. The coefficients A through E depend upon the data interval and cutoff wavelength.

Because the filter is recursive, the signal phase and delay become exaggerated at wavelengths near to and greater than the cutoff wavelength.

Computation of IRI

A post data collection report program is used to compute the International Roughness Index as defined in the World Bank Technical Paper, number 46.

The calculation of IRI is accomplished by computing four variables as functions of the measured profile. These four variables simulate the dynamic response of a reference vehicle traveling over the measured profile. The equations for the four variables are solved for each measured elevation point, except for the first point. The average slope over the first 11 m (0.5 sec at 80 km/h) is used for initializing the variables by assigning the following values:

$$Z'_1 = Z_3' = \frac{(Y_a - Y_1)}{11} \qquad (1)$$

$$Z'_2 = Z'_4 = 0 \qquad (2)$$

$$a = \frac{11}{dx + 1} \qquad (3)$$

where Y_a represents the "a^{th}" profile elevation point, Y_1 is the first point, and dx is the sample interval. Thus, for a sample interval of dx=0.25m, Equation 1 would use the difference between the 45^{th} elevation point and the first elevation point to establish an initial slope for the IRI computation.

The following four recursive equations are then solved for each elevation point, from 2 to n (n= number of elevation measurements).

$$Z_1 = S_{11} * Z'_1 + S_{12} * Z_2' + S_{13} * Z_3' + S_{14} * Z_4' + P_1 * Y' \qquad (4)$$

$$Z_2 = S_{21} * Z'_1 + S_{22} * Z_2' + S_{23} * Z_3' + S_{24} * Z_4' + P_2 * Y' \qquad (5)$$

$$Z_1 = S_{31} * Z'_1 + S_{32} * Z_2' + S_{33} * Z_3' + S_{34} * Z_4' + P_3 * Y' \qquad (6)$$

$$Z_1 = S_{41} * Z'_1 + S_{42} * Z_2' + S_{43} * Z_3' + S_{44} * Z_4' + P_4 * Y' \qquad (7)$$

where,

$$Y' = \frac{(Y_i - Y_{i-1})}{dx} = \text{slope input} \qquad (8)$$

and

$$Z_j' = Z_j \text{ from previous position, j} = 1,4 \qquad (9)$$

and S_{ij} and P_j are coefficients that are fixed for a given sample interval, dx. Thus, Equations 4-7 are solved for each position along the wheel track. After they are solved for one position, Eqn. 9 is used to reset the values of $Z_1', Z_2', Z_3', \text{and } Z_4'$ for the next position. Also for each position, the rectified slope (RS) of the filtered profile is computed as:

$$RS_i = |Z_3 - Z_1| \qquad (10)$$

The IRI statistic is the average of the RS variable over the length of the site. Thus after the above equations have been solved for all of profile points, the IRI is calculated as:

$$IRI = \frac{1}{(n-1)} \sum_{i=2}^{n} RS_i \qquad (11)$$

The above procedure is valid for any sample interval between dx=.25m and dx=.61m (2 ft.). For shorter sample intervals, the additional step of smoothing the profile with an average value is recommended to better represent the way in which the tire of a vehicle envelopes the ground. The base length for averaging is 0.25m long. The IRI can then be calculated in either of two ways:

1) The elevation points falling within each .25m of length may be averaged to obtain an equivalent profile point for the .25m interval. Then the IRI is calculated from the above equations based on a .25m interval using the coefficients for the .25m interval.

2) A "moving average" is obtained as the average of all points falling within a .25m equations for each averaged point using coefficients in the equations appropriate for the interval centered on the profile elevation point. Then the IRI is calculated by solving the smaller interval.

A half car simulation of IRI is also available when the dual accelerometer data is collected. The half car simulation is attained by first taking the average of the left and right profiles, point by point. Next, the averaged data points are used in the quarter car simulation and rectified slope calculation as previously described for one wheel path.

RUT DEPTH MEASUREMENT AND ANALYSIS

Rut Depth Measurement

The Road Profiler's provides two methods of rut depth measurement using either 3 height sensors or 5 height sensors. These are illustrated in Figure 3.

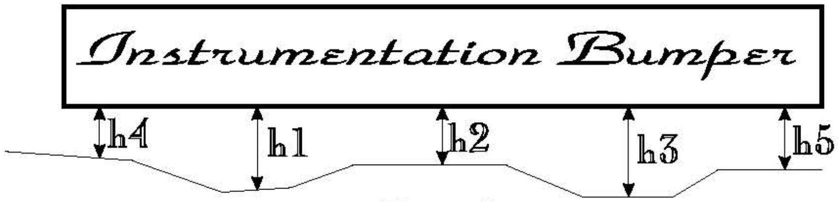


Figure 3

Three ultrasonic ranging devices are positioned in the test vehicle's instrumentation bumper. They are collinear and equidistant from each other, normally spaced 34.5 inches apart to match highways' predominant rut spacings. At every other profile measurement point, the three sensors measure the distance to the pavement surface. A quantity which approximates the average of left and right rut depth is computed according to the relationship

$$R = \frac{(h_1 - h_2 + h_3)}{2}$$

where h_1, h_2 and h_3 are the respective distances between the pavement and the left, center, and right sensors. R actually represents the height of the hump between the wheelpaths.

The five sensor system makes the measurement more like that using a straight edge across each wheelpath. This arrangement has the advantage of allowing separate left and right rut depth measurements using sensors mounted outside the wheelpath sensors. The five sensor system allows collection by either three sensors or five sensors. When data is collected by five sensors it can be also reported like it was collected by three sensors for comparison.

The basic accuracy of the 5 sensor rut depth measurement has been verified to be approximately one-sixteenth of an inch where as the 3 sensor rut is one-eighth of an inch if the test vehicle maintains an accurate course with the sensors positioned above the wheelpaths. Certain factors can affect this accuracy, however. The three-sensor system and sometimes the five-sensor system cannot detect asphalt pavement which has shoved upward adjacent to the rut, so rut depths may be underestimated. Measurements in "dual wheel" ruts caused by heavy trucks on soft pavements are also less precise. Even though the measured rut depth is slightly inaccurate, a rutting problem is still clearly indicated. The three sensor measurement can report large errors where the center of the wheelpaths contain a crown while the five sensor system will accurately determine the rut.

Although rut depths are typically measured at one foot intervals, the post processing report program allows the user to give the average rut depth measurement at selected intervals of 50 ft or more.

3 SENSOR RUT DEPTH CALCULATION

Reference Figures 4 and 5

$$h_1 = h_2 + RD_L - d_1 \sin\theta \qquad (1)$$
$$RD_L = h_1 - h_2 + d_1 \sin\theta \qquad (2)$$

$$h_1 = h_3 + H_3 - (d_1 + d_2)\sin\theta \qquad (3)$$
$$H_3 = RD_L - RD_R \qquad (4)$$

Using eq.1, 3, and 4

$$h_2 + RD_L - d_1 \sin\theta = h_3 + RD_L - RD_R - (d_1 + d_2)\sin\theta$$
$$RD_R = h_3 - h_2 - d_2 \sin\theta$$

$$RD_{total} = RD_L + RD_R$$
$$= h_1 - h_2 + d_1 \sin\theta + h_3 - h_2 - d_2 \sin\theta$$
$$= h_1 + h_3 - 2h_2 + (d_1 - d_2)\sin\theta$$

Since the center sensor is equally spaced between the outside sensors,

$$d_1 - d_2 = 0$$
$$RD_{total} = h_1 + h_3 - 2h_2$$

$$RD_{Avg} = \frac{RD_{total}}{2} = \frac{h_1 + h_3 - 2h_2}{2}$$

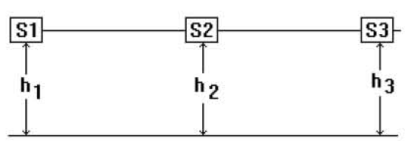


Figure 4

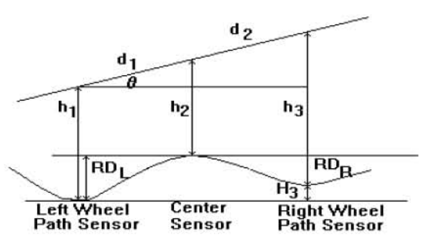
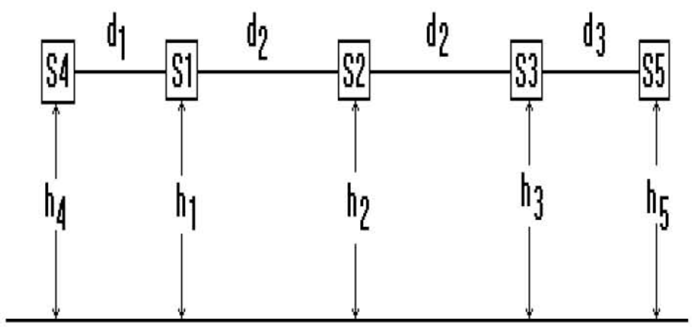
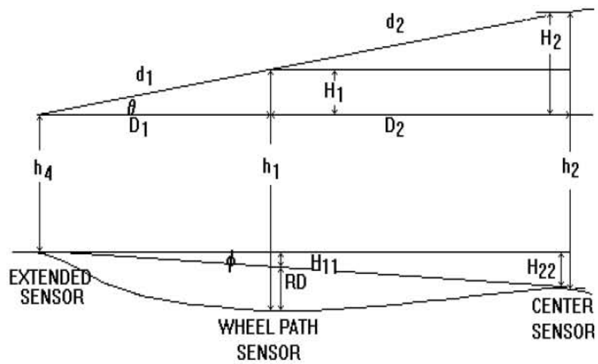


Figure 5

<u>**5 SENSOR RUT DEPTH CALCULATION**</u>
Reference Figures 6 and 7



5 SENSOR CONFIGURATION
Figure 6



5 SENSOR MEASUREMENT DIAGRAM

Figure 7

$$\text{Left RD} = h_1 - \frac{d_1 h_2 + d_2 h_4}{d_1 + d_2}$$

substituting

h_3 for h_1, h_5 for h_4, and d_3 for d_1

$$\text{Right RD} = h_3 - \frac{d_3 h_2 + d_2 h_5}{d_3 + d_2}$$

The profiler stores the field detected error information with the height sensor data and the report program has features to check the point to point comparison on each height sensor. The point to point data can also be used to detect faulting on concrete. The two outboard sensors maybe placed in a transverse position to detect faulting while the remaining three can be used for three sensor type rut depth.

Precision profiling instrument

Hand Operated Survey Products

Walking Profiler G2

Introduction

The Walking Profiler G2 is an efficient, accurate and precise instrument for collecting and presenting continuous paved surface information. Outputs include: Distance, Profile, Grade and International Roughness Index (IRI). The WP G2 meets World Bank Class 1 Profilometry requirements.

This compact and easy to use device is accepted by PIARC (2002), FHWA (2000) and TxDOT (2000) as a reference tool for the calibration of roughness measuring equipment.

The WP G2 samples the pavement surface at a walking pace. The built-in data acquisition module collects and stores the data while displaying the results in real-time.

The WP G2 is supplied with Footworks software, which is a fully featured data processing and reporting package. Reporting utilities are available for International Roughness Index (IRI), California Profilograph (CP) emulation and Straight Edge (SE) simulation.

Features and Benefits

- A custom data acquisition module with high visibility LCD screen
- Operates in bright sunlight and is backlit for operation in poor light
- Simple 5 button operation with a user-friendly touchscreen that controls all setup and survey functions
- Light weight device is easily transported
- Extended operation from rechargeable battery (>8 hours operation)
- Easy snap-in snap-out battery replacement
- Easy on-site setup procedures that minimise startup times

Applications

- Provides accurate measurements of true profile, grade and level
- Reference tool for calibrating and assessing high speed profilers
- Suitable for many surfaces, including: Paved roads and footpaths, Airfields and runways, Building slabs, Sporting surfaces, Bridges, Carparks etc.

Precision profiling instrument

Specification Summary

Condition	Requirement
Outputs	True profile height and grade against distance
Speed of Operation	800 metres/hour. Controlled walking pace, with audible speed prompt
Units	Metric or Imperial
Data Format	ASCII data, comma seperated
Sampling interval (length)	241.3 mm (9.50 inches)
Distance Accuracy	typical error $< \pm 0.3\%$ (texture dependent)
Height measurement precision	$\pm$ 0.01 mm ($\pm$ 0.0004 inches) per step
Height resolution	$<$ .005 mm (0.0002 inches) per step
Profile accuracy	$\pm$1.0 mm per 50 metres ($\pm$0.04 inches per 50 yds) of smooth surface (typical)
Profilometry class	World Bank Class 1
Output Parameters	International Roughness Index (IRI), California Profilograph (CP) emulation* and Straight Edge (SE) simulation*
IRI Accuracy	$\pm$ 0.1 metres per km ($\pm$ 6.3 inches per mile) on high quality pavements
Correlation with rod and level derived IRI	$R^2 = 0.999$
Wavelength measuring limits	0.5 metres to hundreds of metres (0.5 yds to hundreds of yds) no defined upper limit
Maximum grade measurement	1 in 6 or 9.5 degrees
Minimum path curvature	15 metres (16 yds) radius
Warm up time	10-20 minutes
Battery Life	>8 hours (without LCD backlight activated)
Working surfaces	Should be dry, firm, mud and dust free. Paved surfaces should be swept free of stones and debris.
Operating temperature	0 - 45°C or 32 - 113°F

Components

- Walking Profiler
- Data Acquisition module
- Footworks Data Processing and Reporting Utilities software (*optional Advanced Reporting Utilities)
- Data Download Cable
- Battery Charger

Hand Operated Survey Products

Walking Profiler G2

Note: ARRB Group Ltd reserves the right to change these specifications without notice. Whilst every care is taken in preparing these specifications, ARRB recognises that there may be classes of surface and applications for which the device has not been tested, and for which the device may not meet the stated specifications

Authorised Agent:

ARRB Group Ltd
500 Burwood Hwy
Vermont South VIC 3133
AUSTRALIA

T: +61 3 9881 1555
F: +61 3 9887 9820
productinfo@arrb.com.au
www.arrb.com.au

arrb GROUP technology

PB-WalkingProfilerG2 0205 V1.1

APPENDIX B:

APPENDIX C:

APPENDIX B:

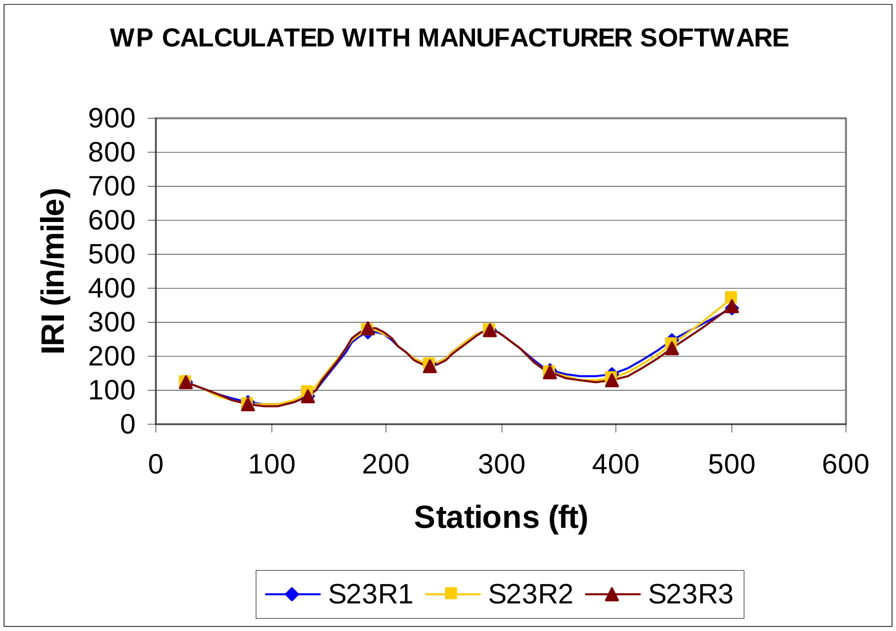


Figure B1: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

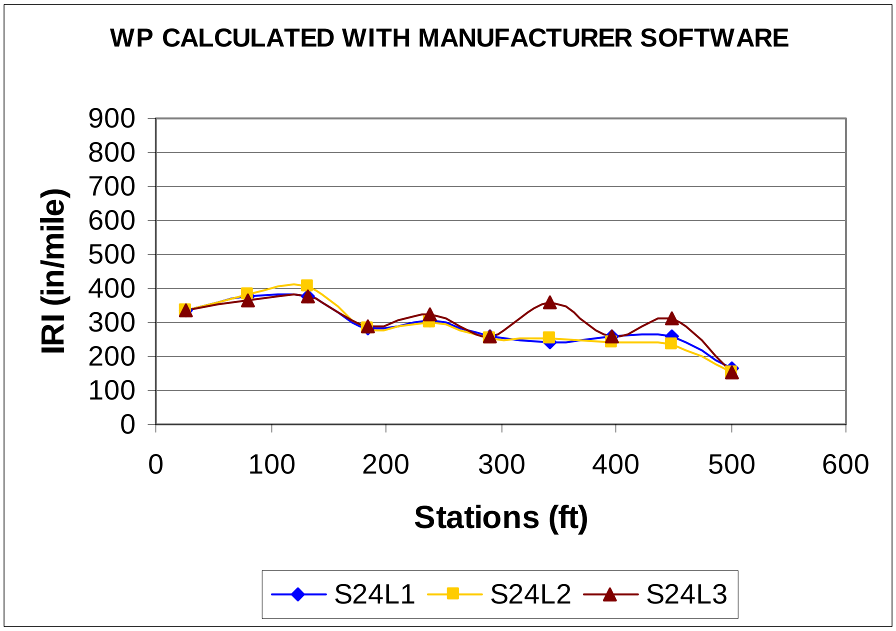


Figure B2: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

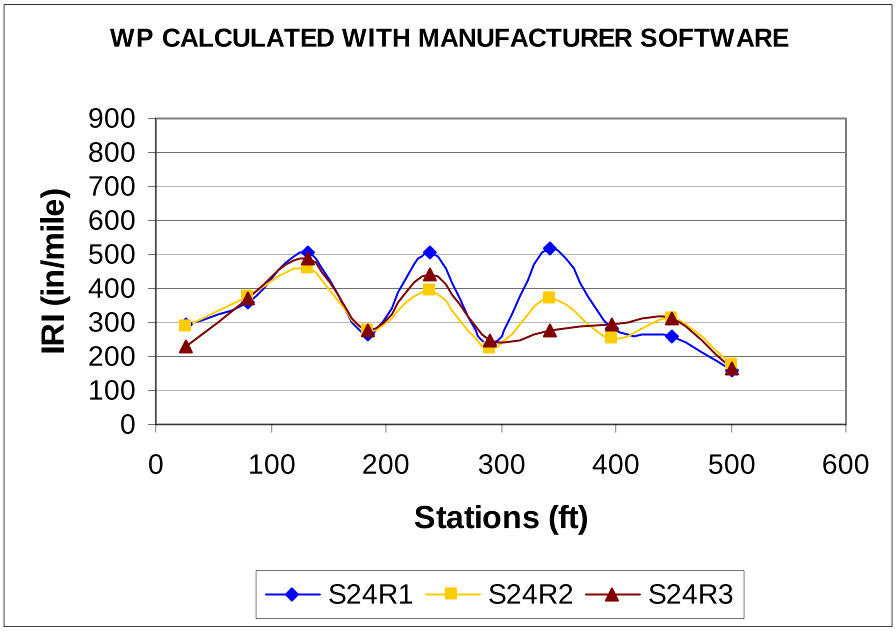


Figure B3: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

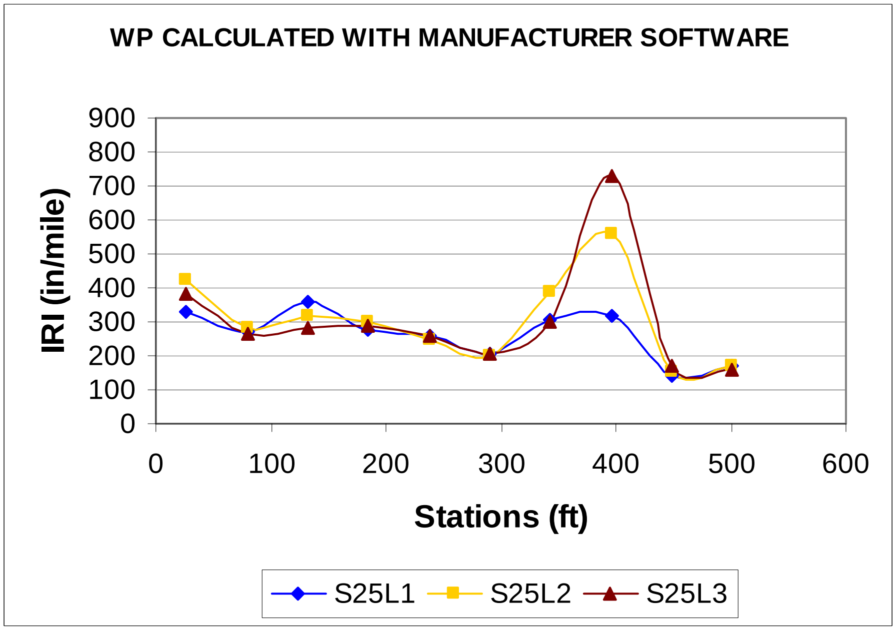


Figure B4: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

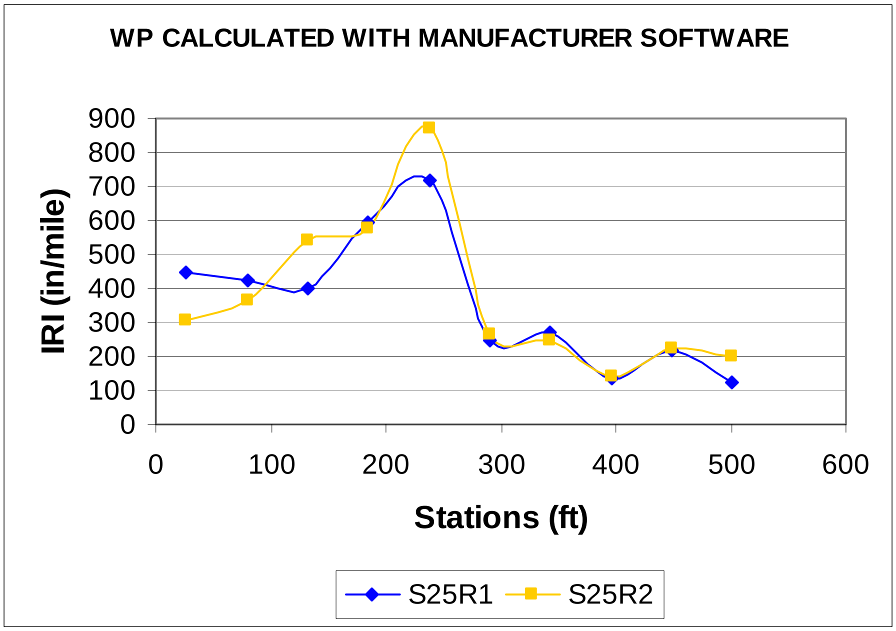


Figure B5: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

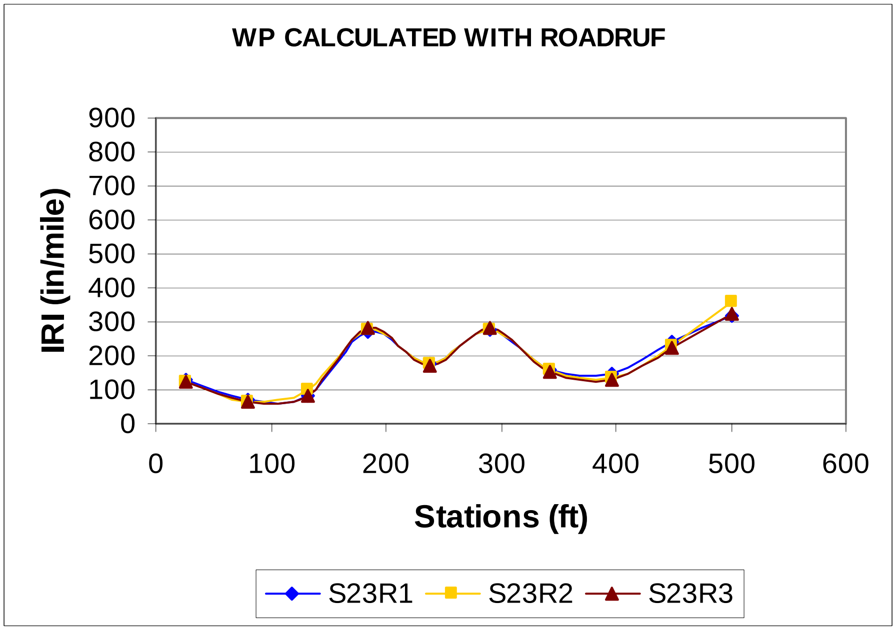


Figure B6: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

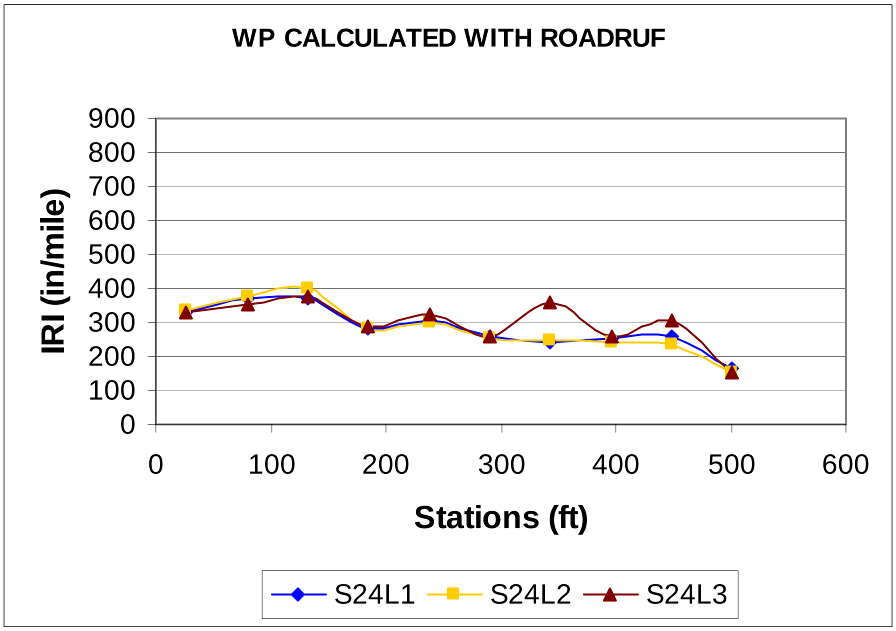


Figure B7: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

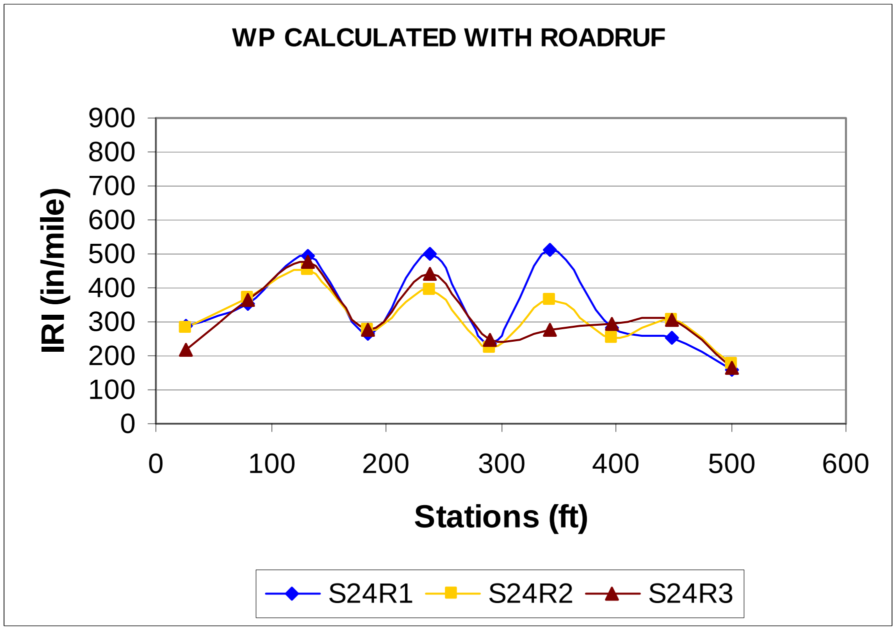


Figure B8: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

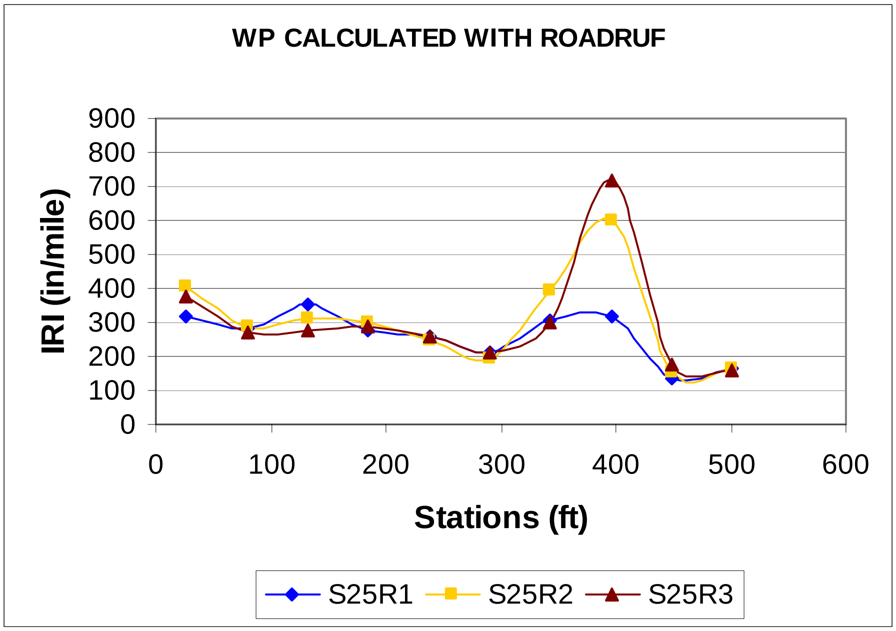


Figure B9: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

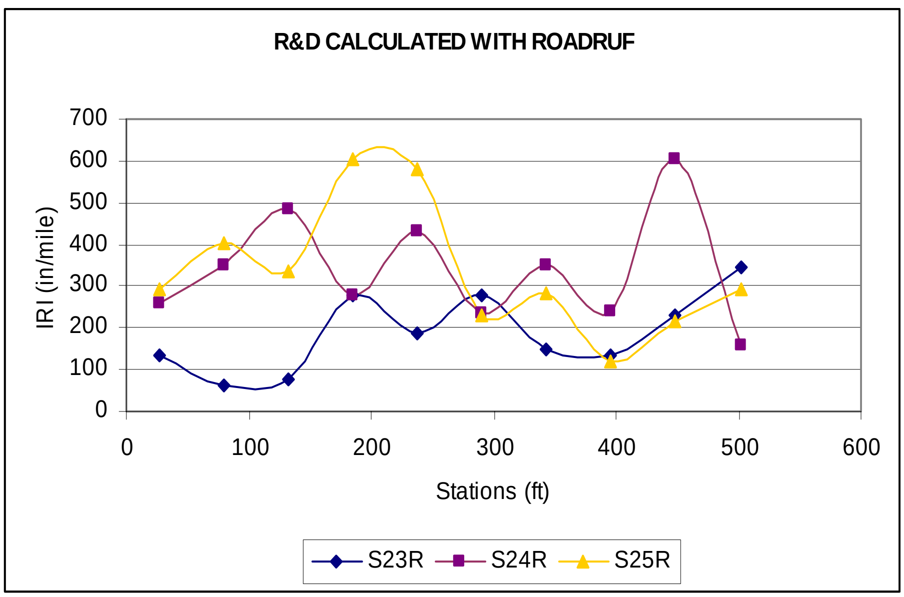


Figure B10: IRI, Route 18, Relatively Rough, Sections 23, 24, and 25 Right Wheel Path

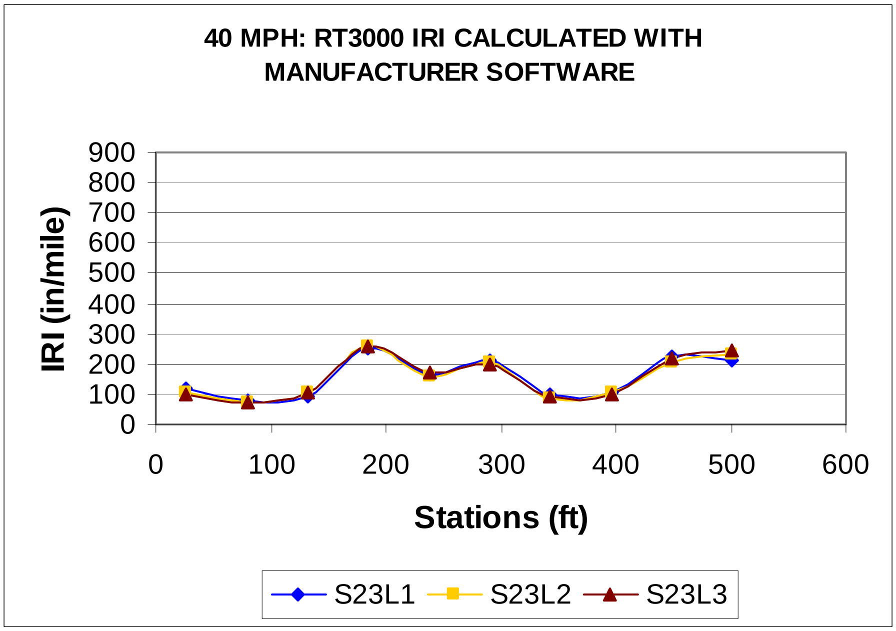


Figure B11: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

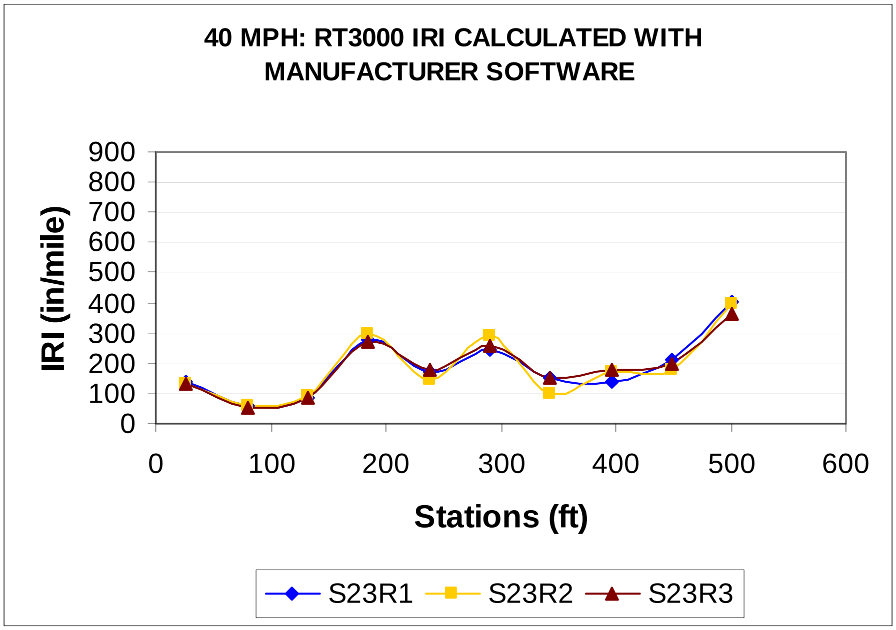


Figure B12: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

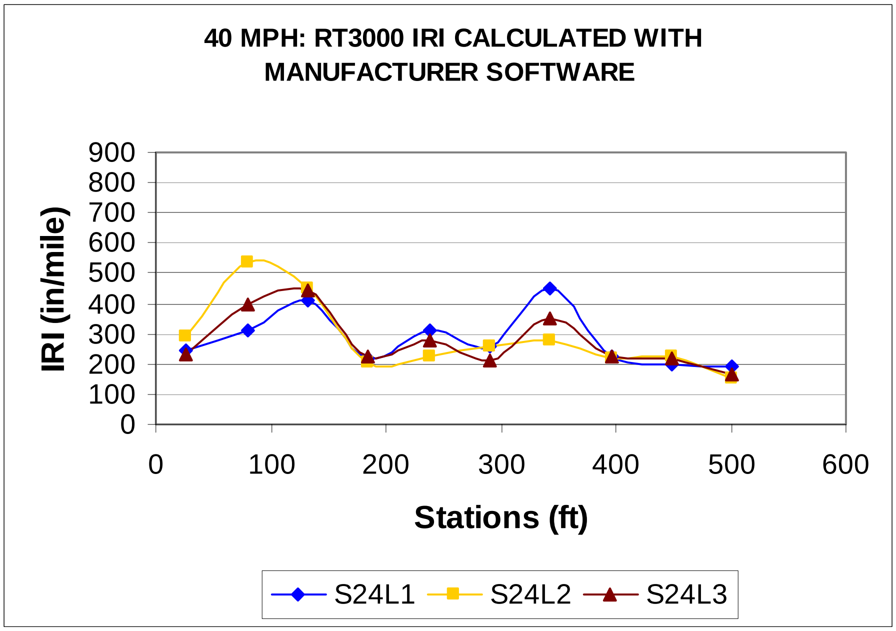


Figure B13: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

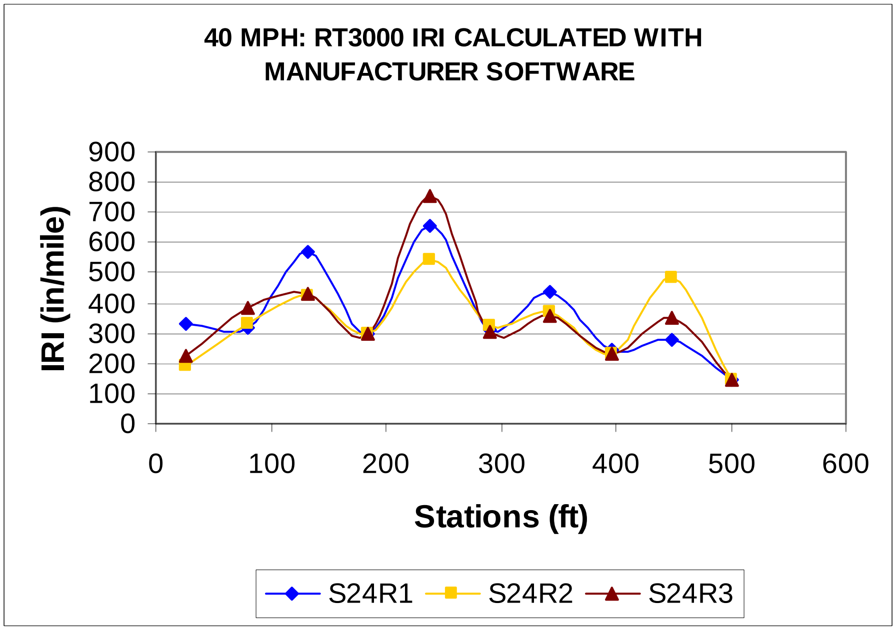


Figure B14: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

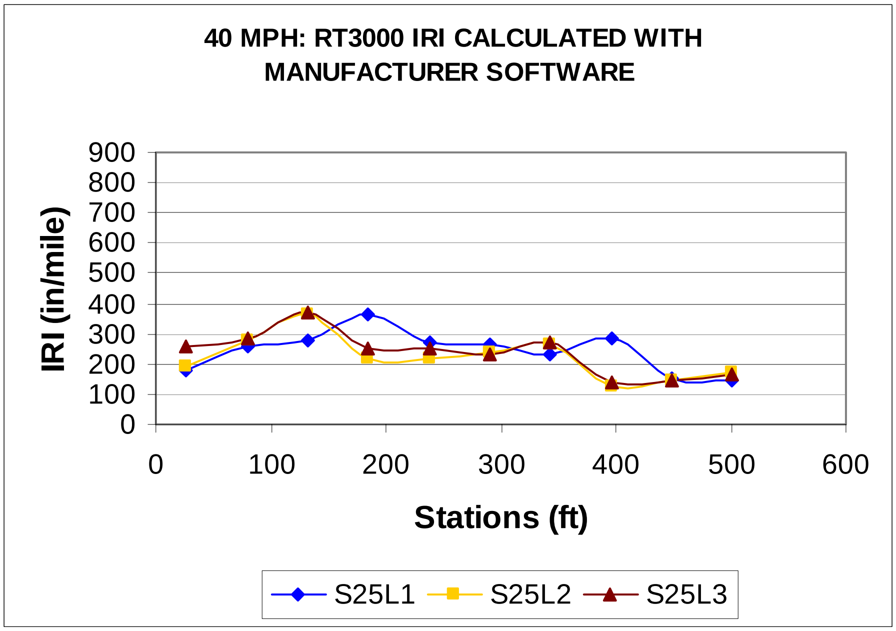


Figure B15: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

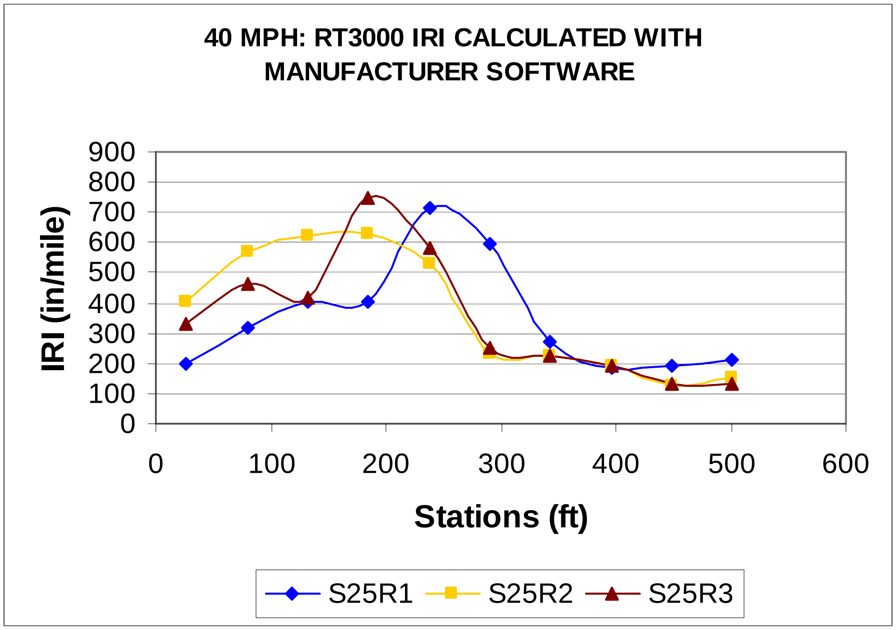


Figure B16: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

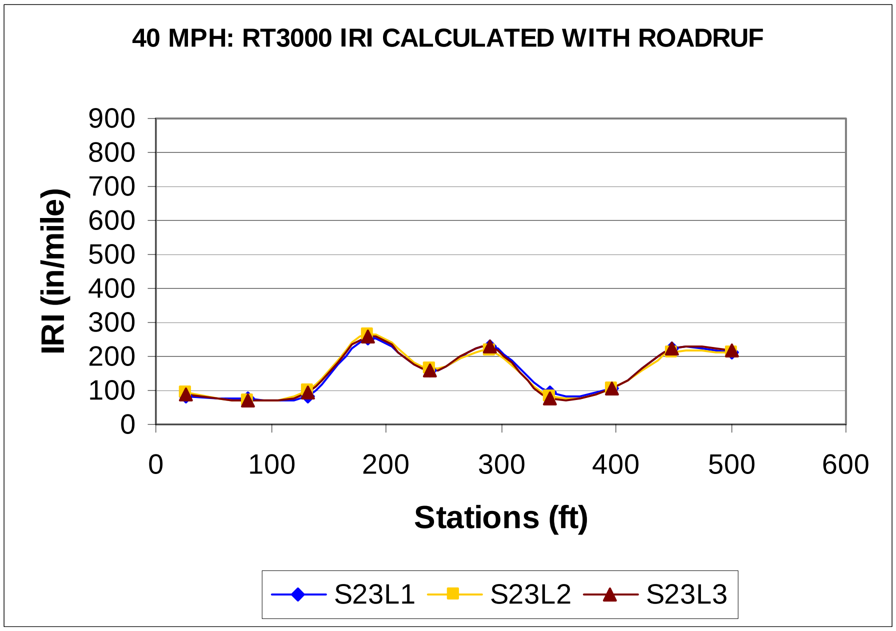


Figure B17: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

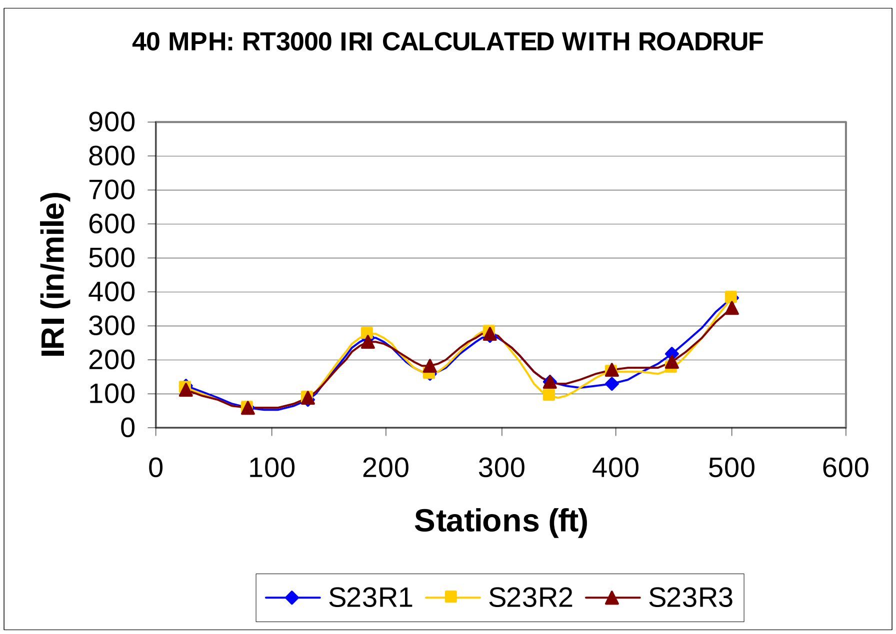


Figure B18: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

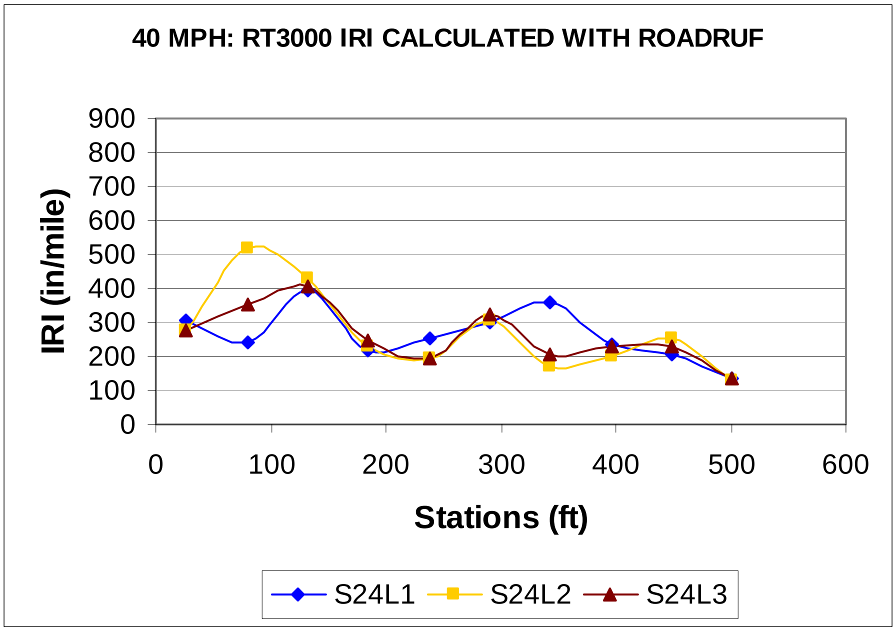


Figure B19: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

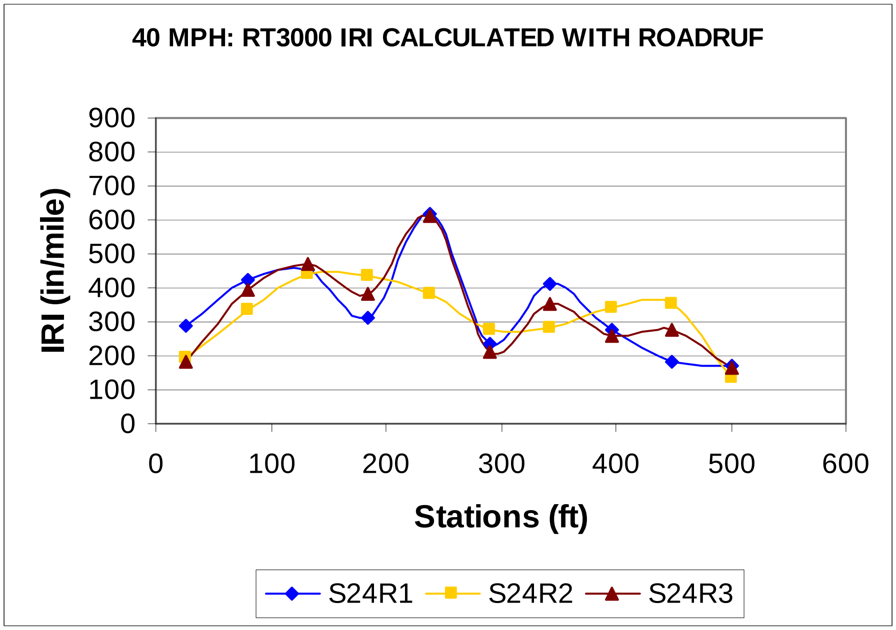


Figure B20: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

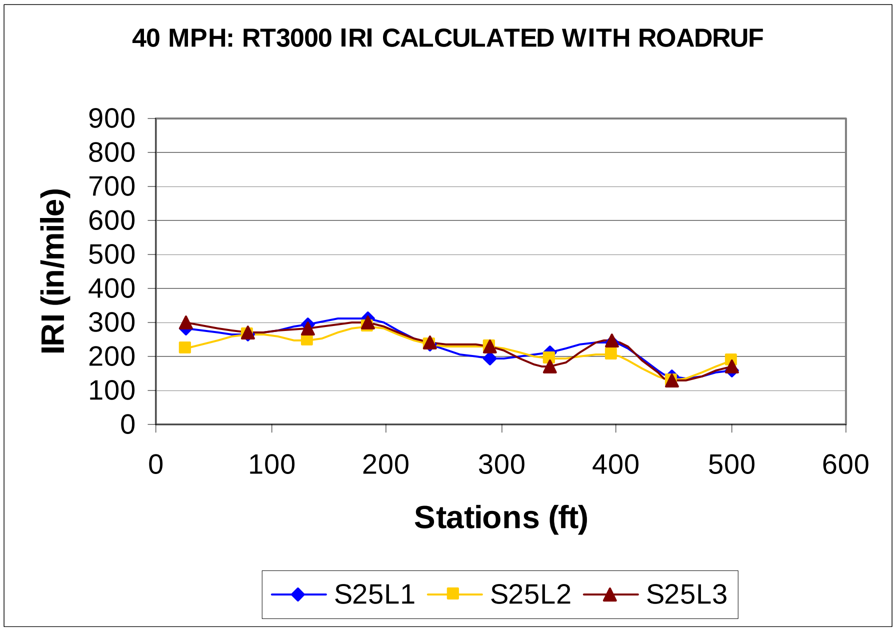


Figure B21: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

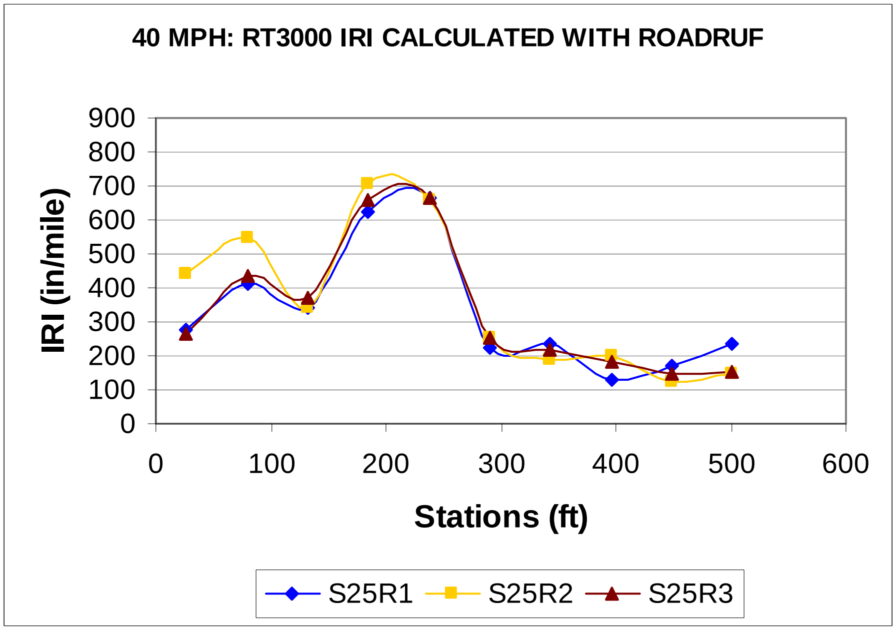


Figure B22: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

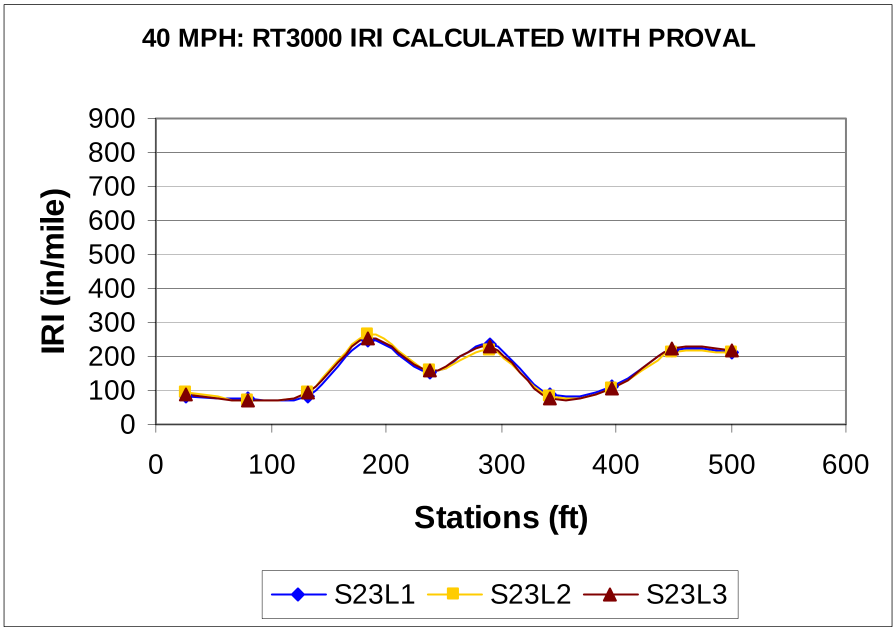


Figure B23: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

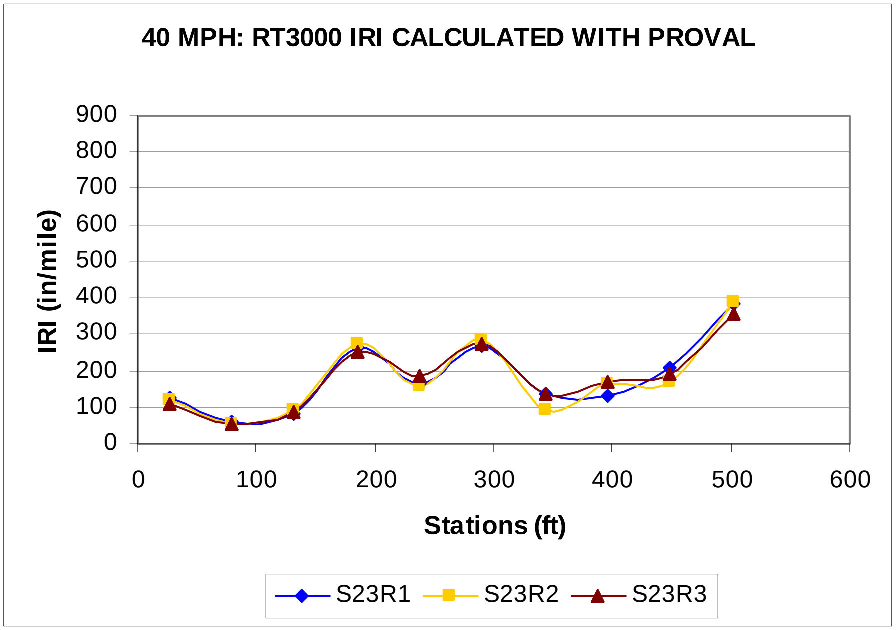


Figure B24: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

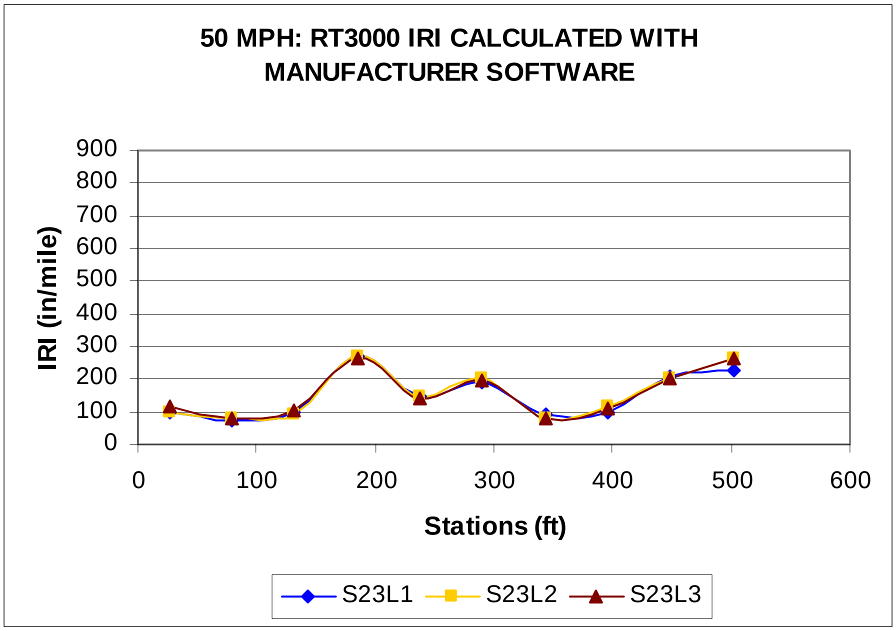


Figure B25: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

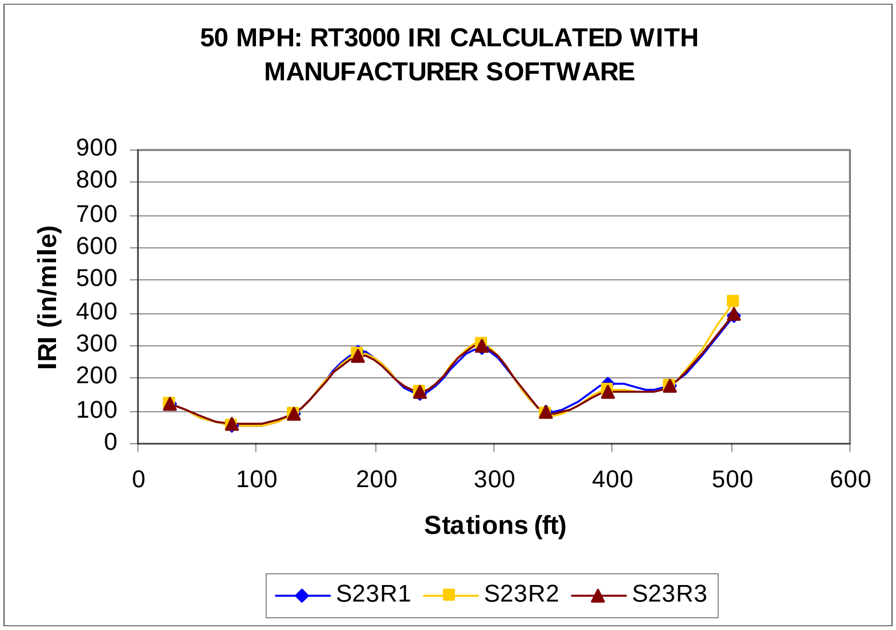


Figure B26: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

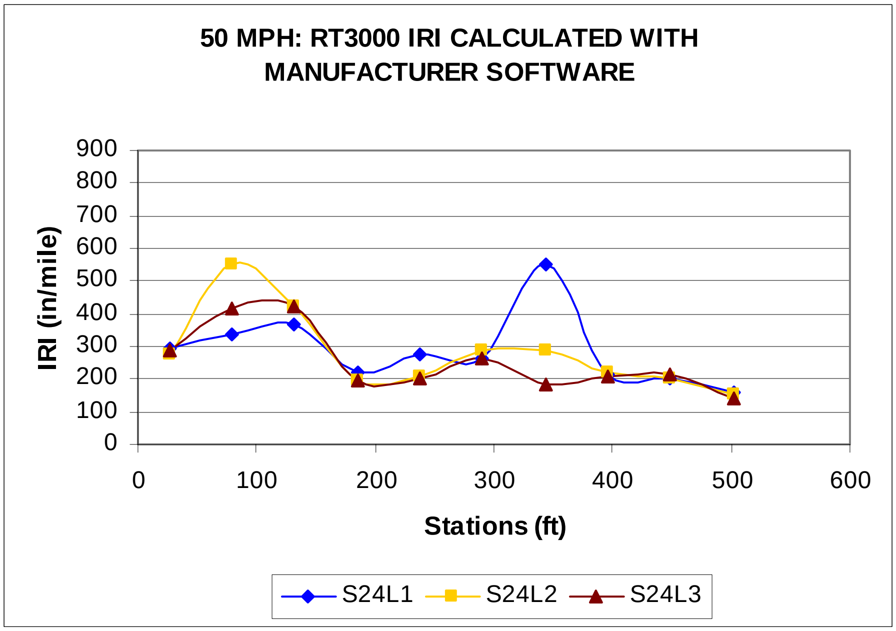


Figure B27: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

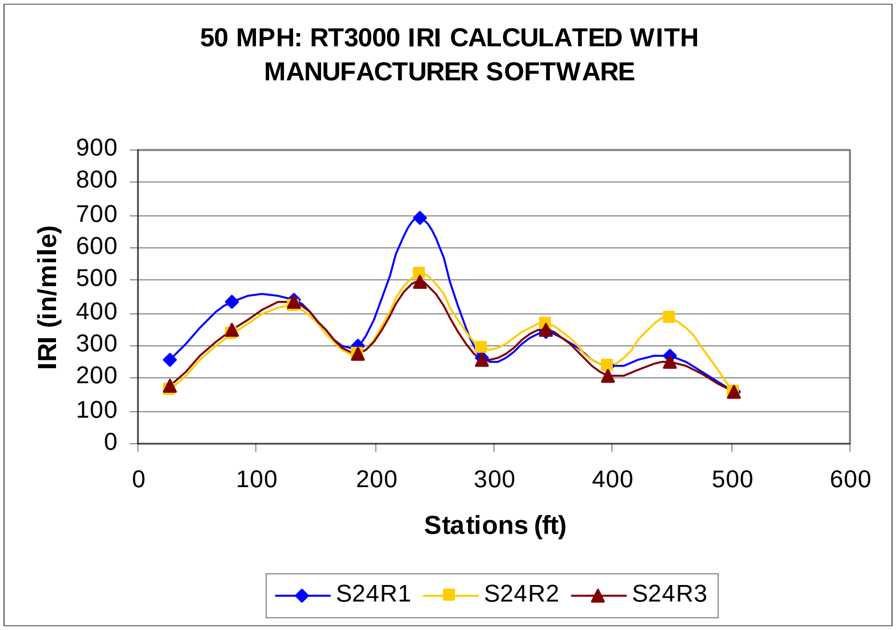


Figure B28: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

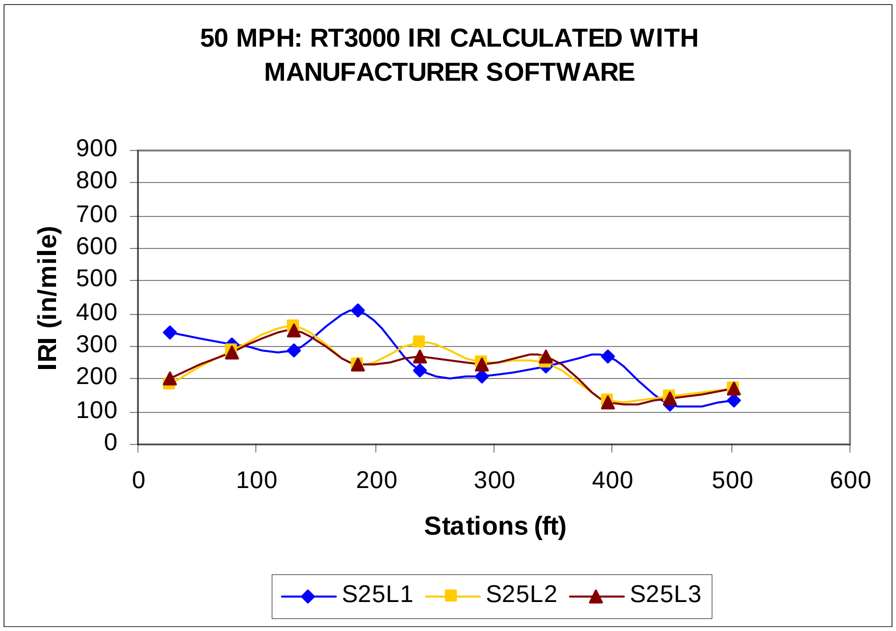


Figure B29: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

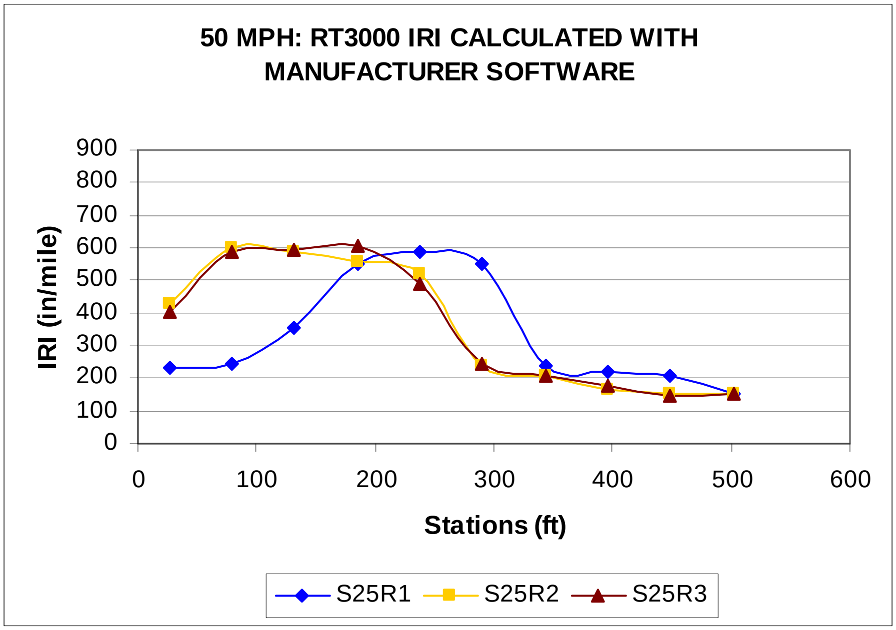


Figure B30: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

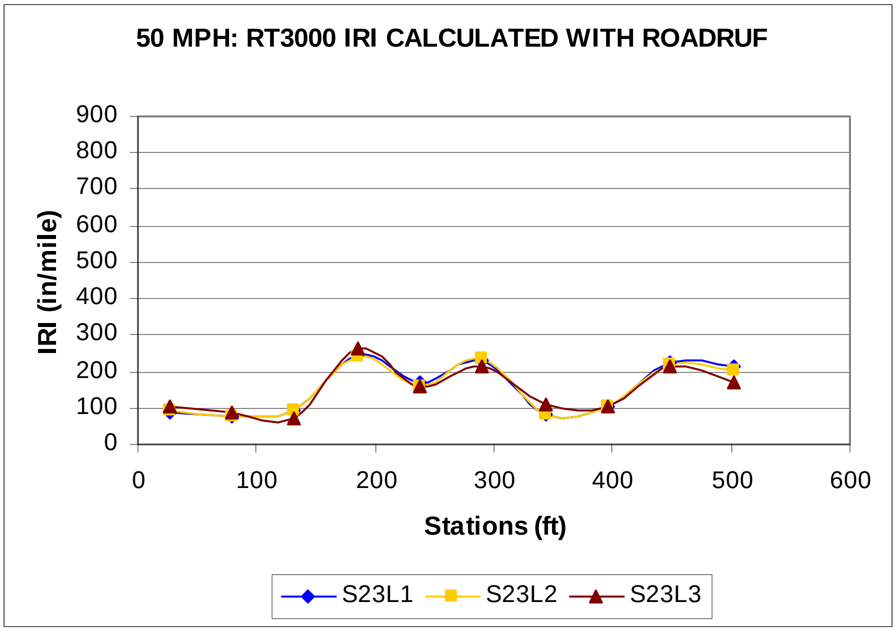


Figure B31: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

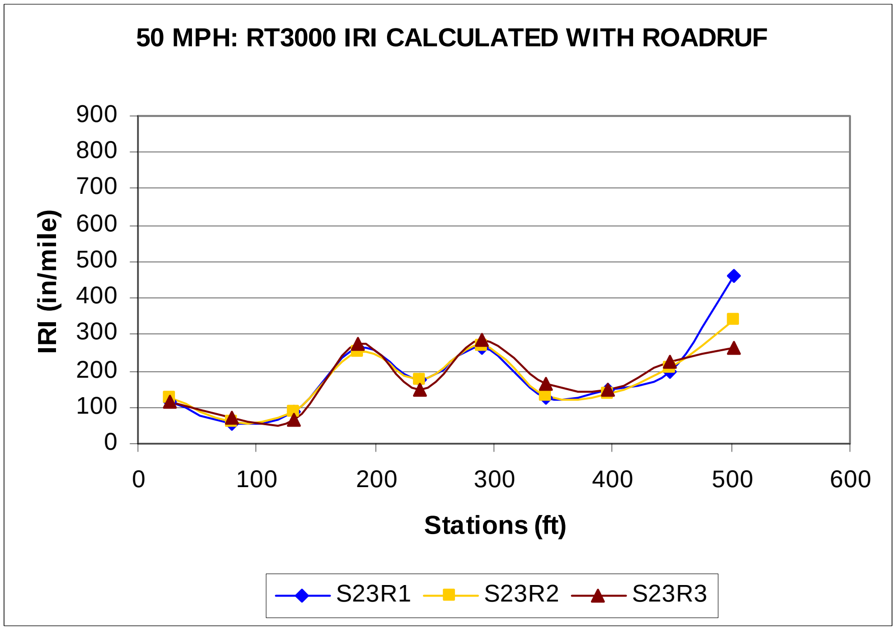


Figure B32: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

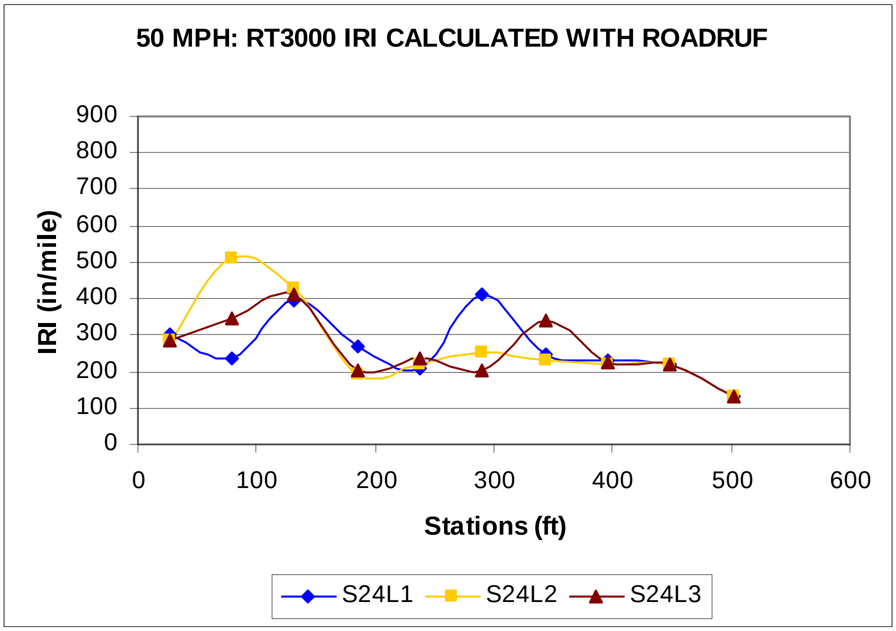


Figure B33: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

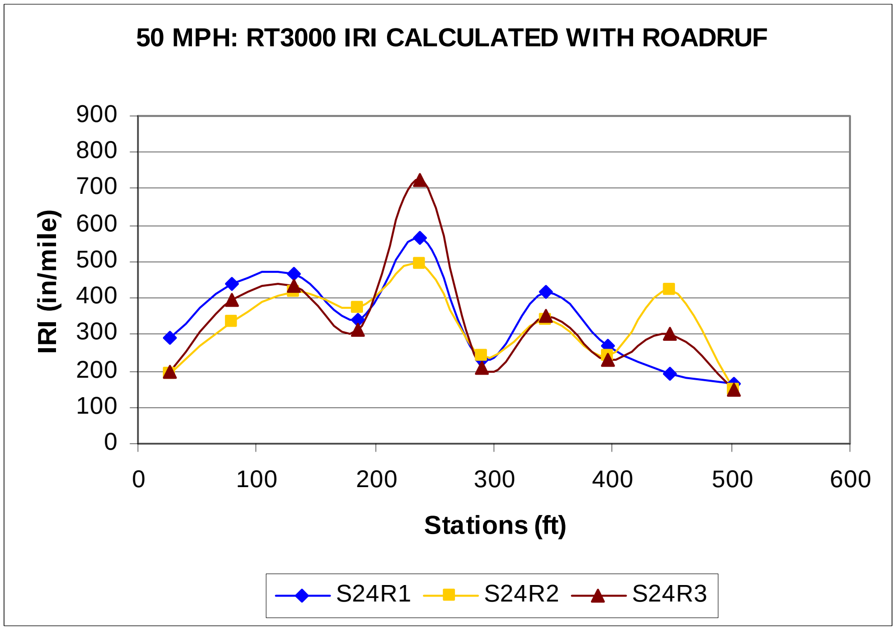


Figure B34: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

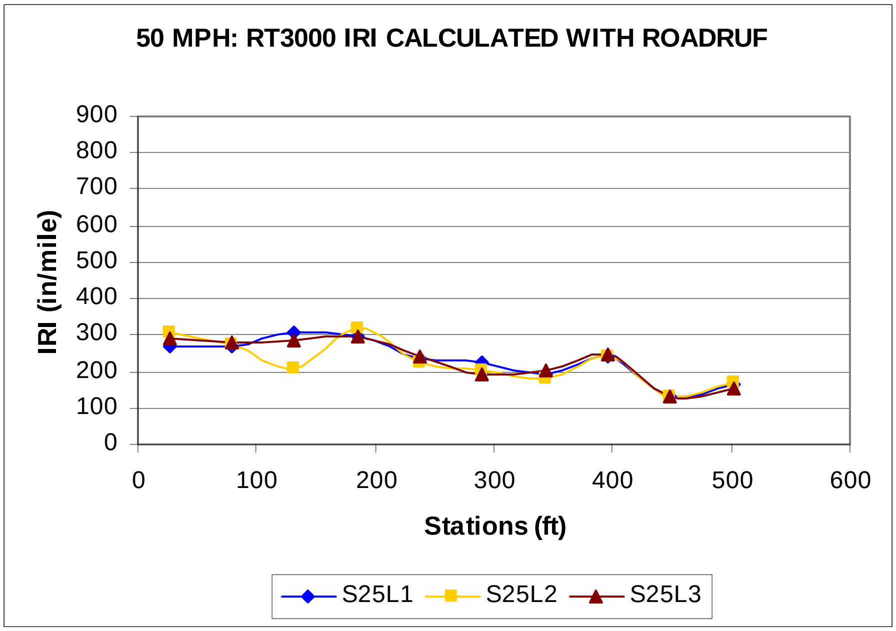


Figure B35: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

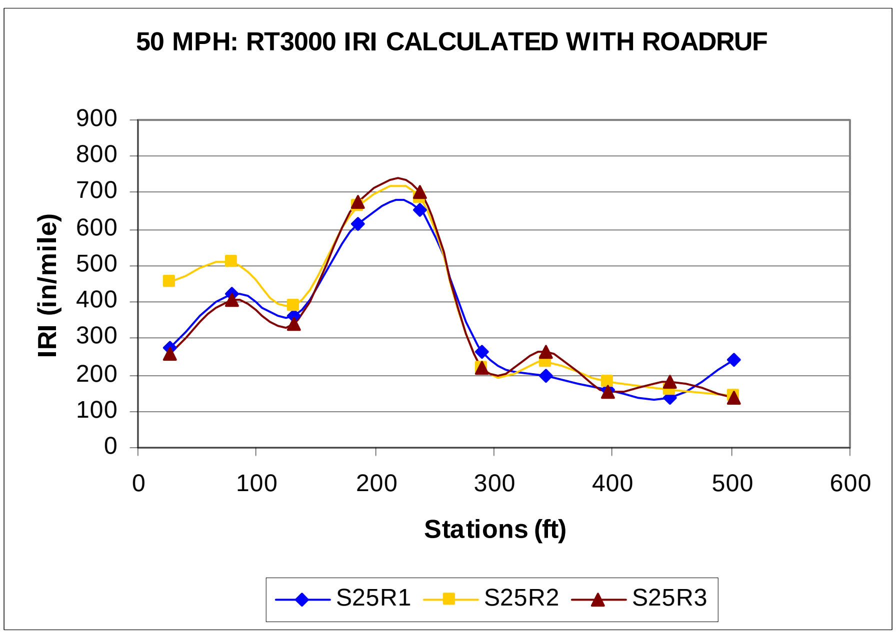


Figure B36: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

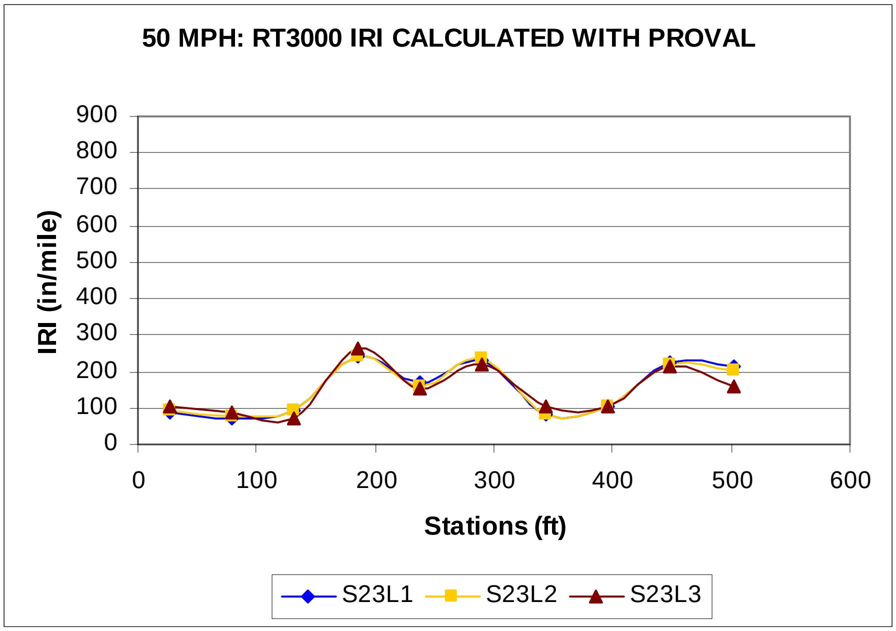


Figure B37: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

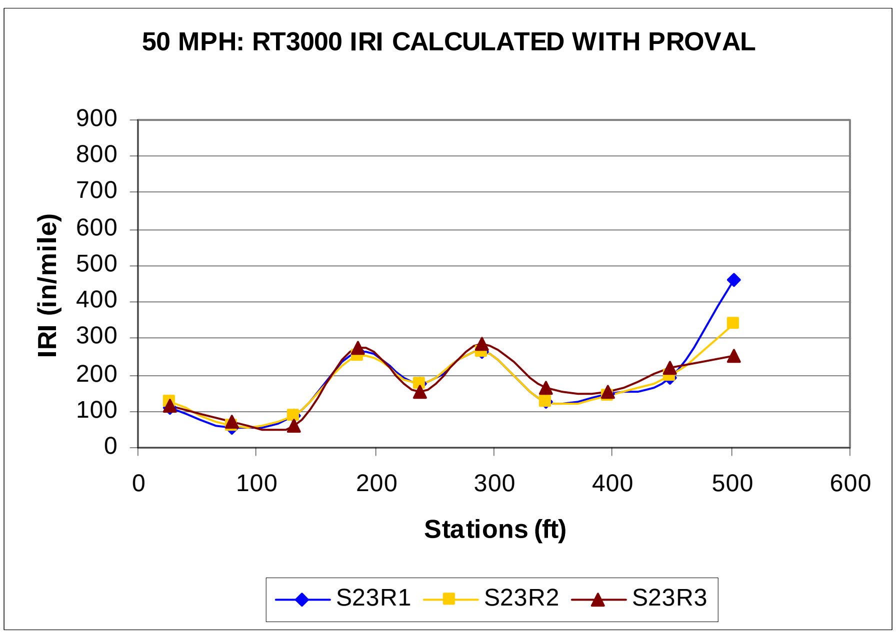


Figure B38: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

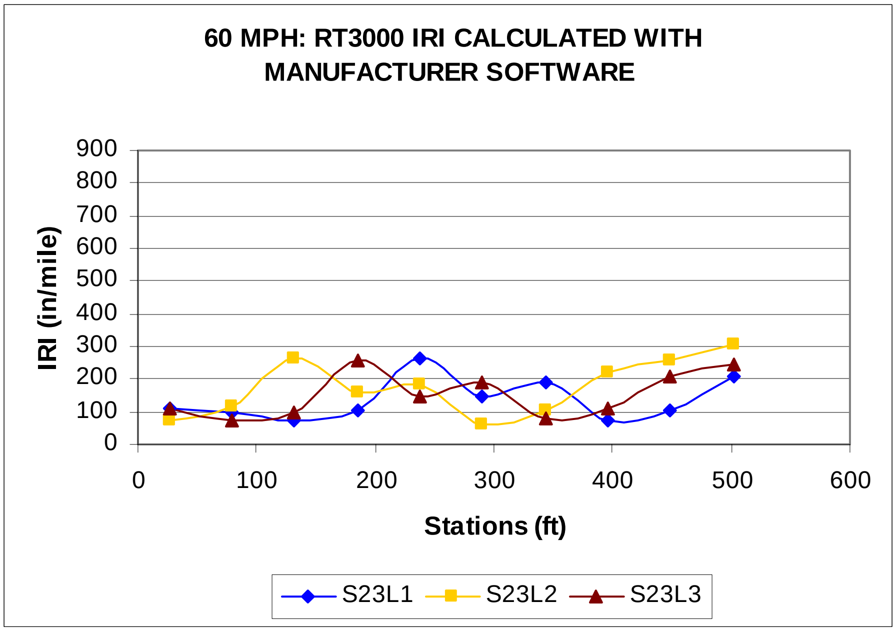


Figure B39: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

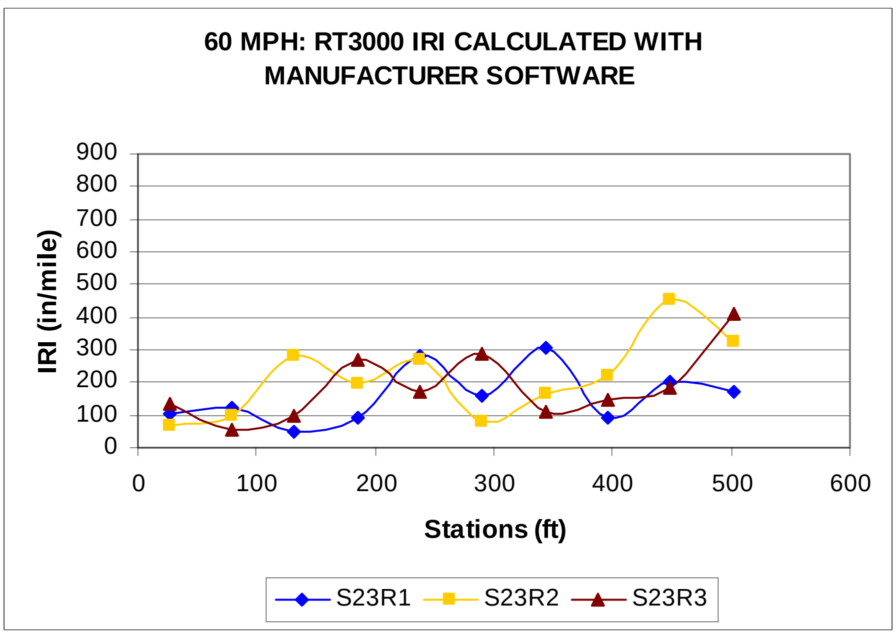


Figure B40: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

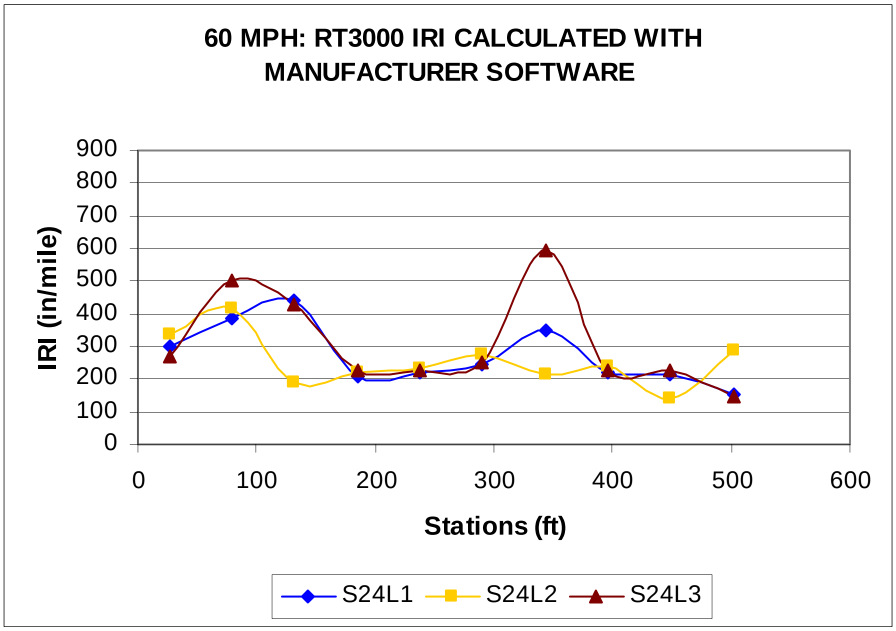


Figure B41: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

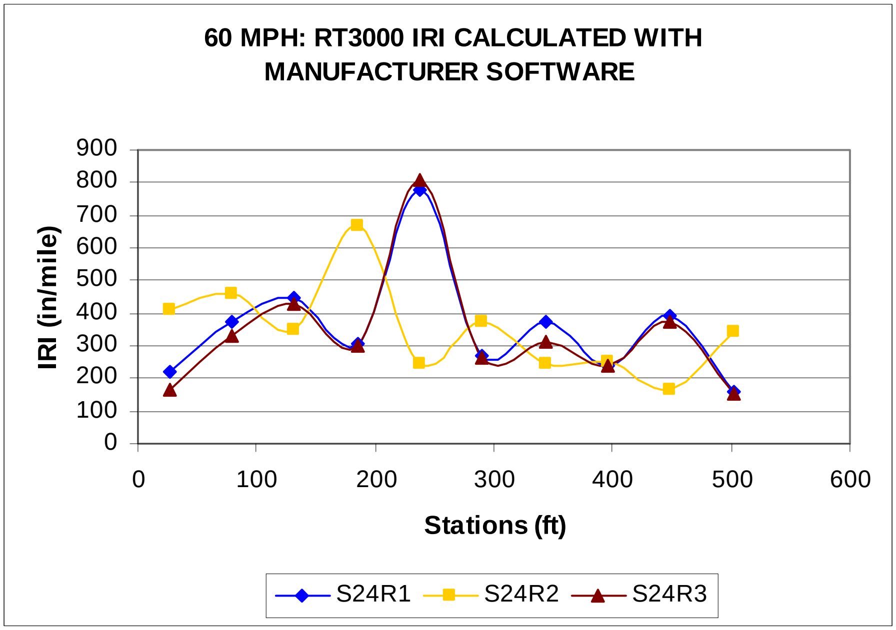


Figure B42: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

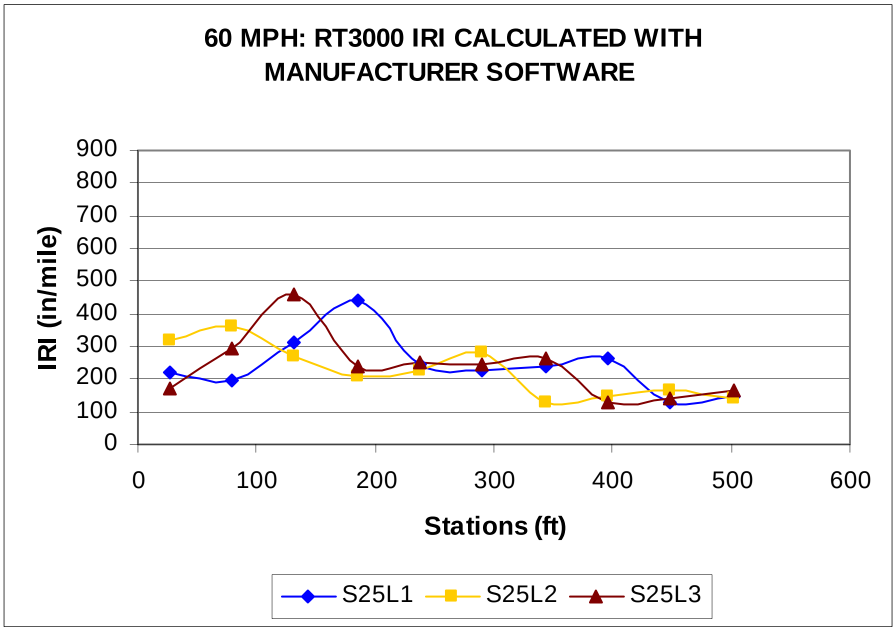


Figure B43: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

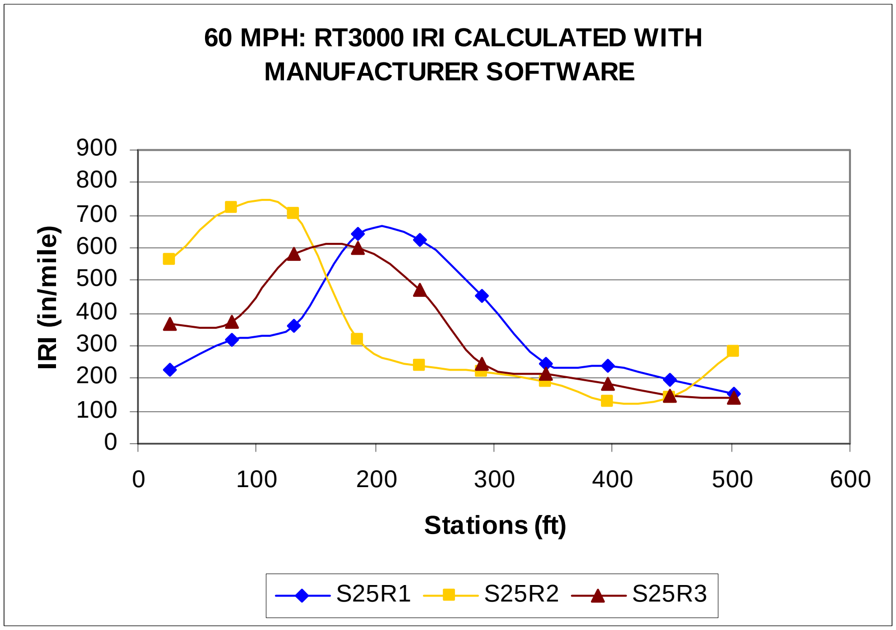


Figure B44: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

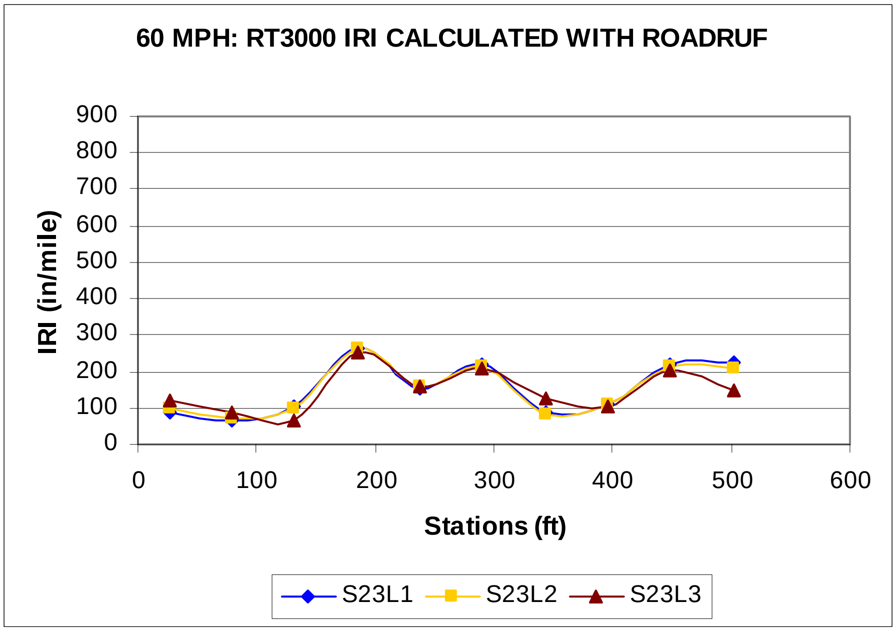


Figure B45: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

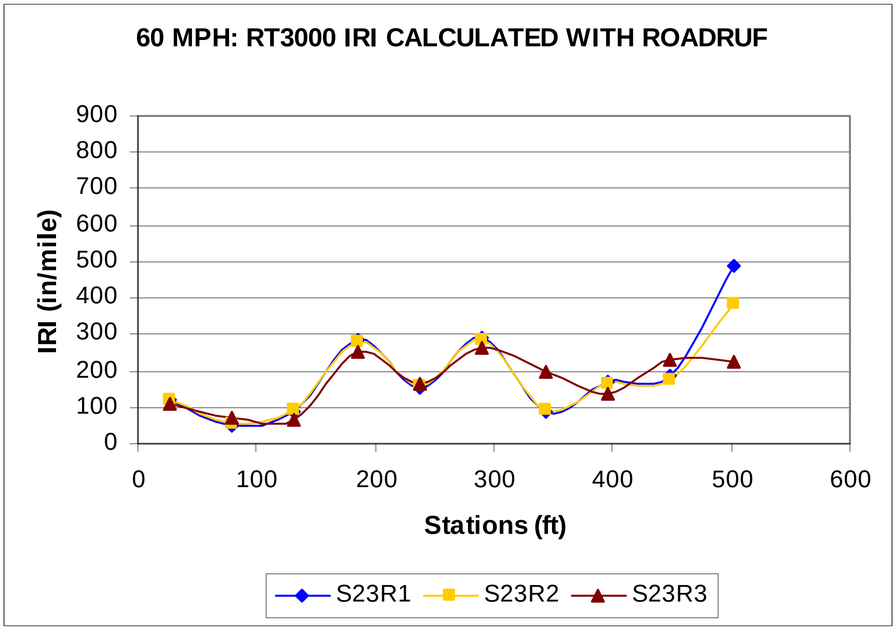


Figure B46: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

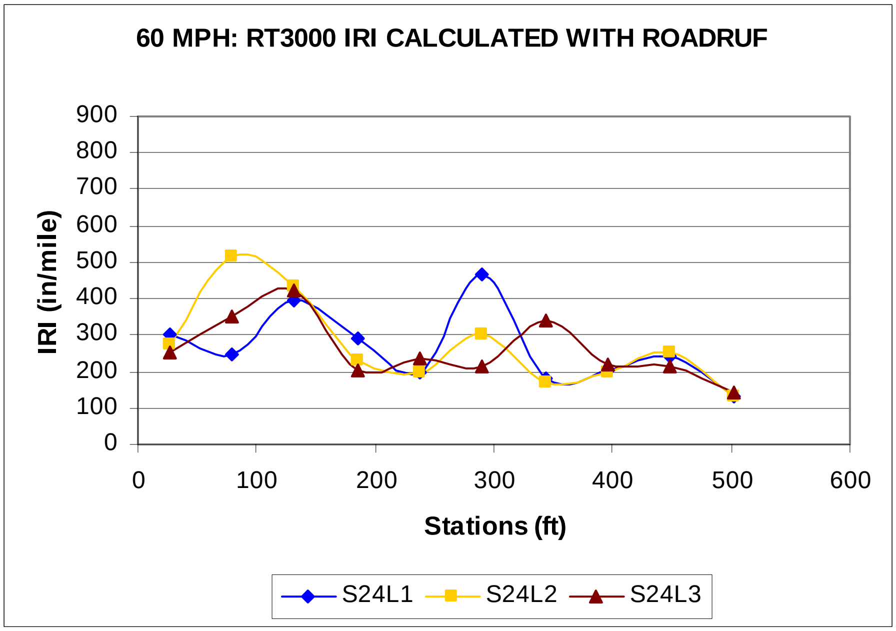


Figure B47: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

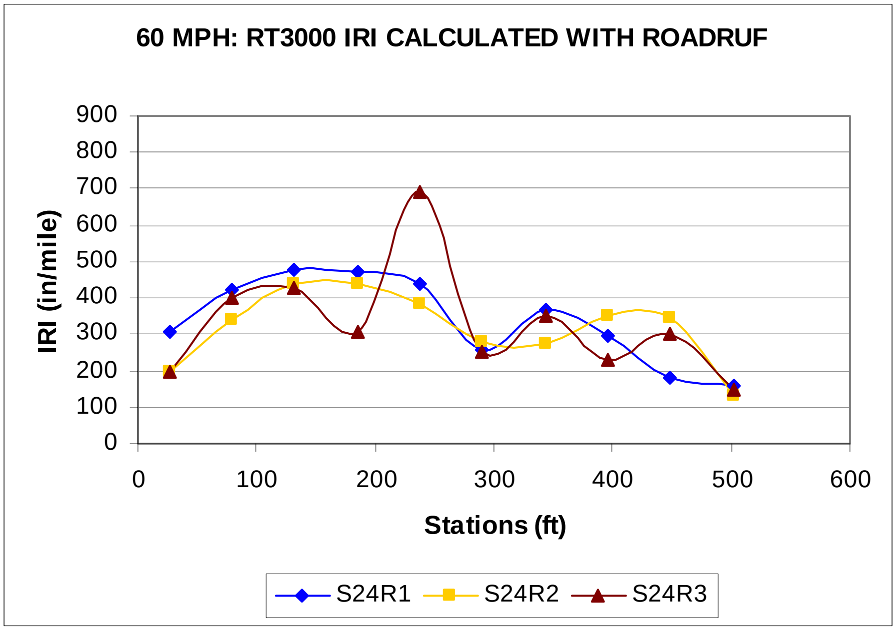


Figure B48: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

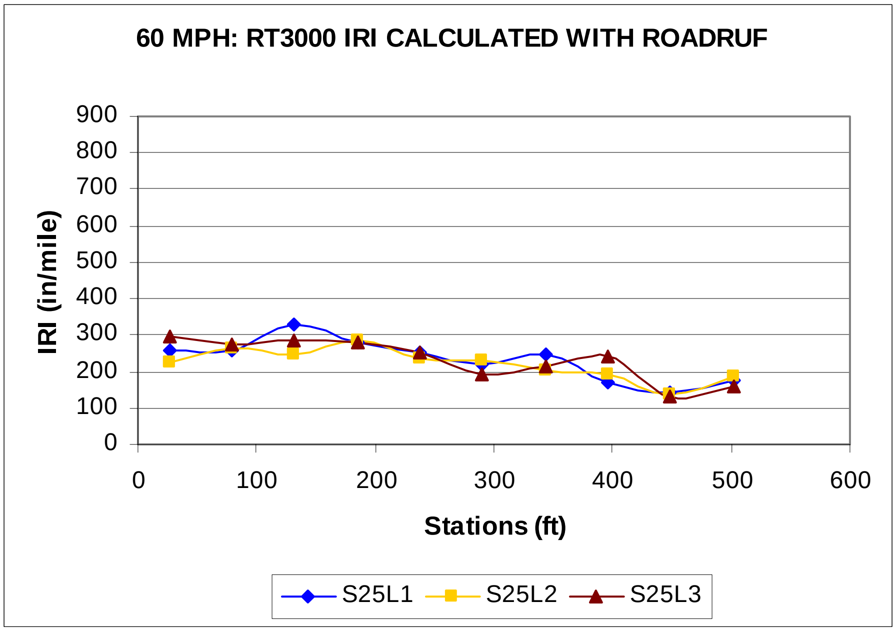


Figure B49: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

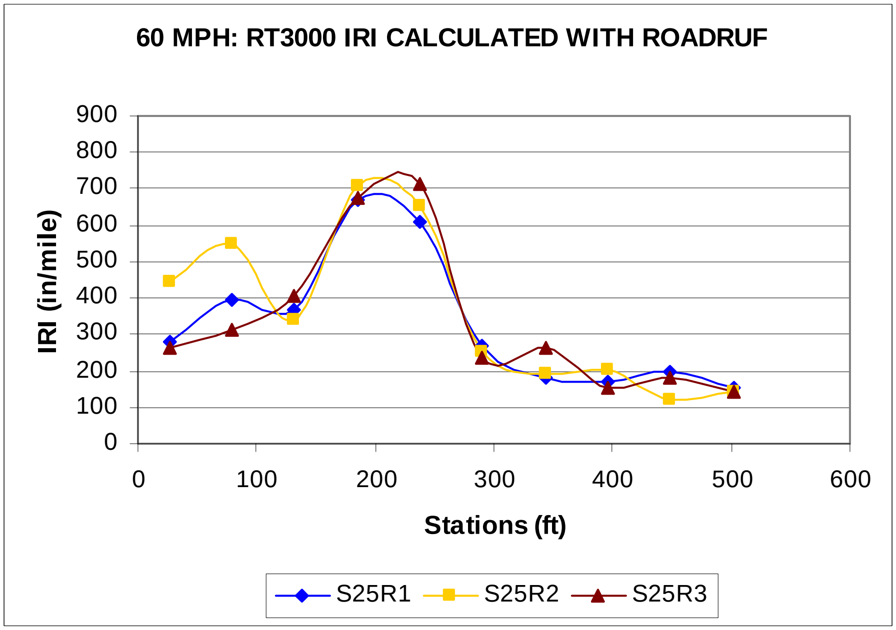


Figure B50: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

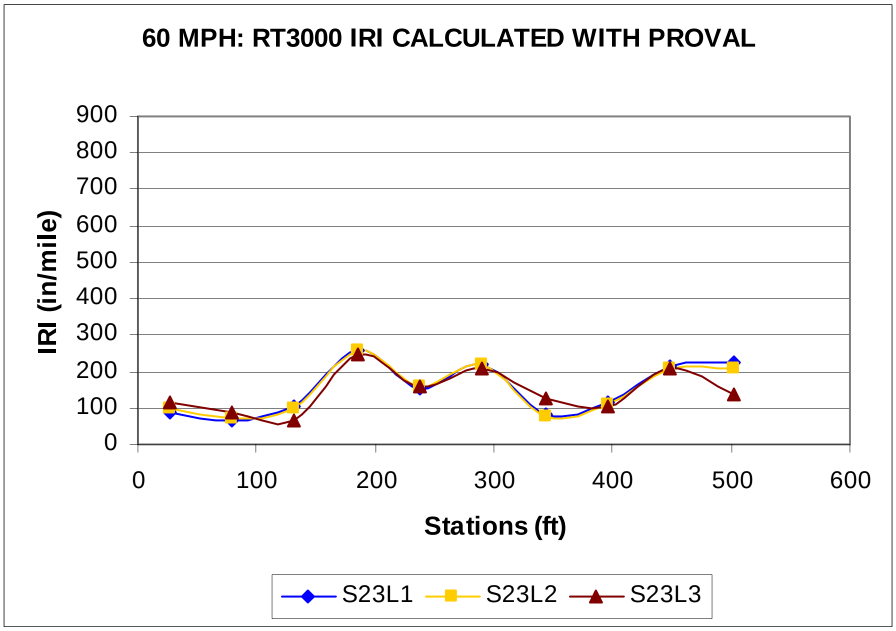


Figure B51: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

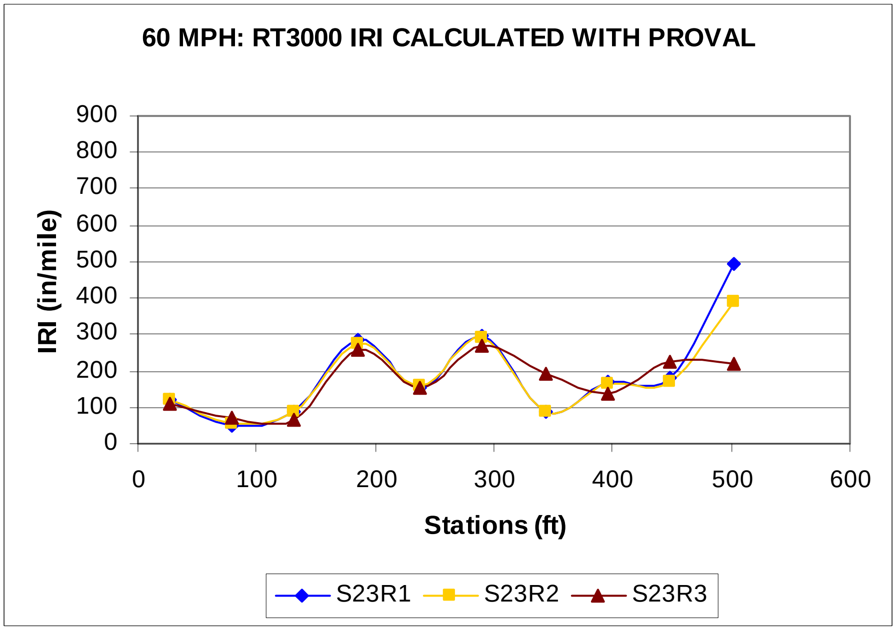


Figure B52: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

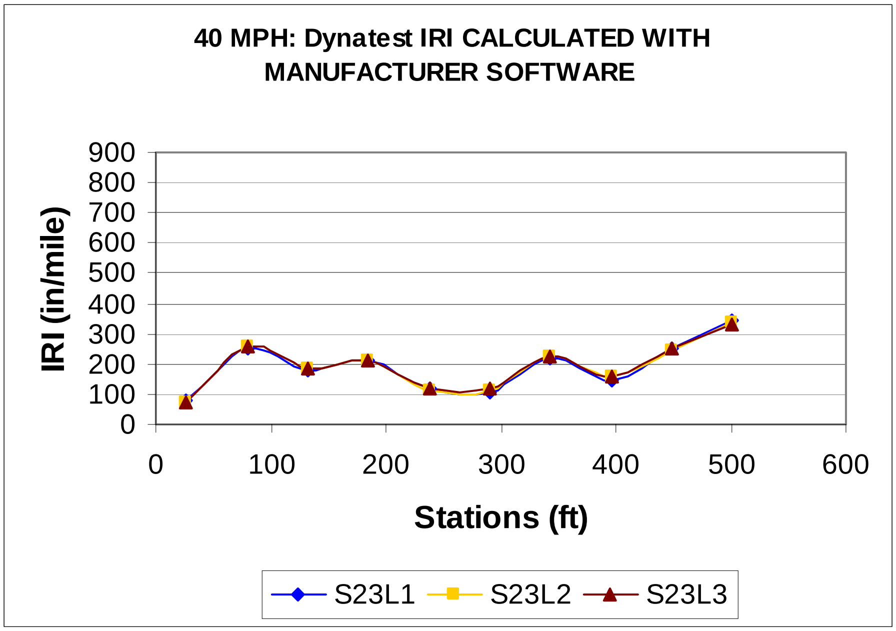


Figure B53: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

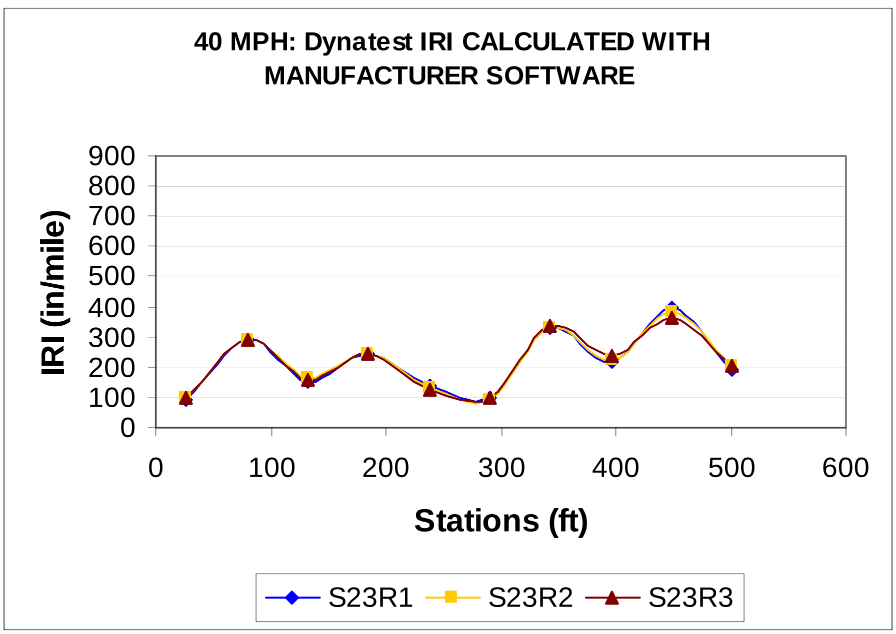


Figure B54: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

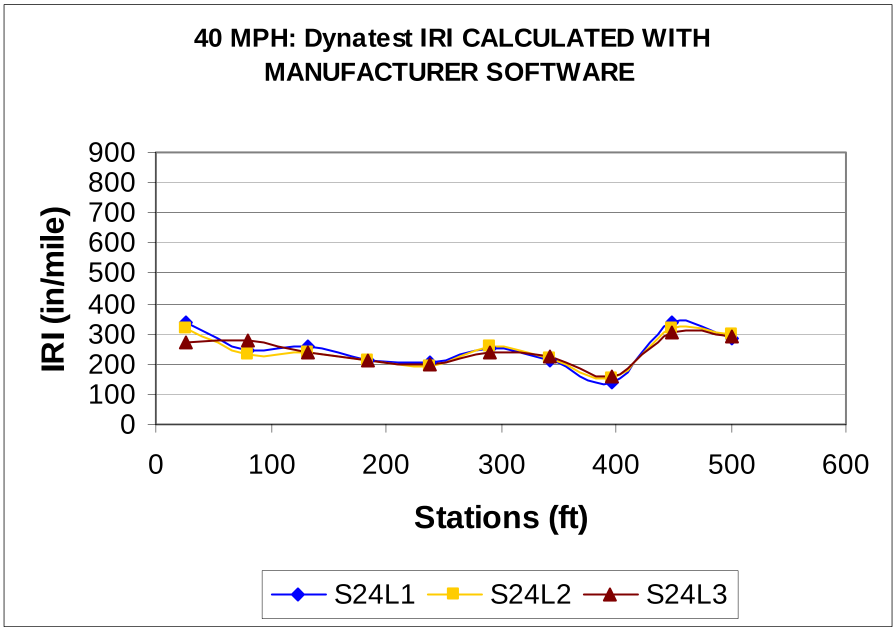


Figure B55: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

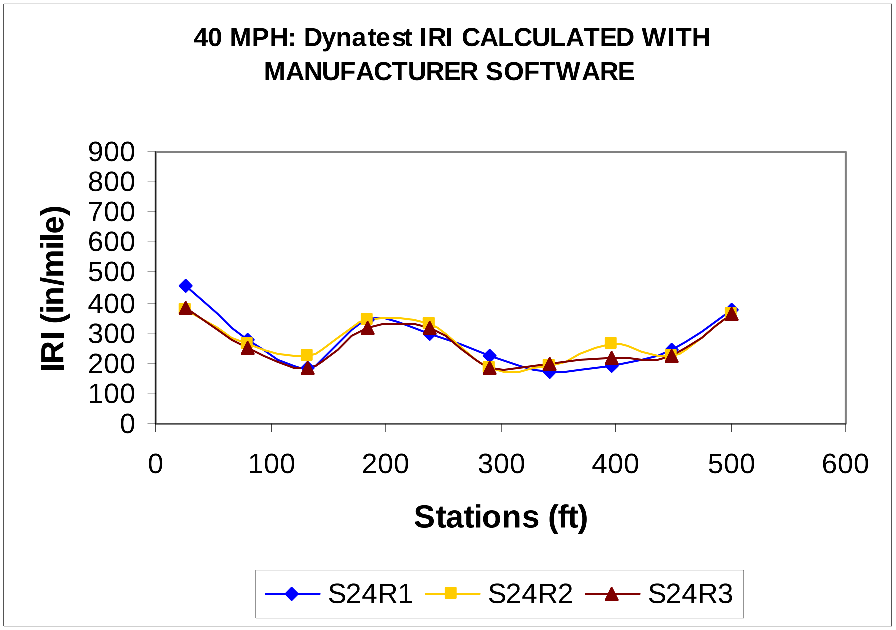


Figure B56: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

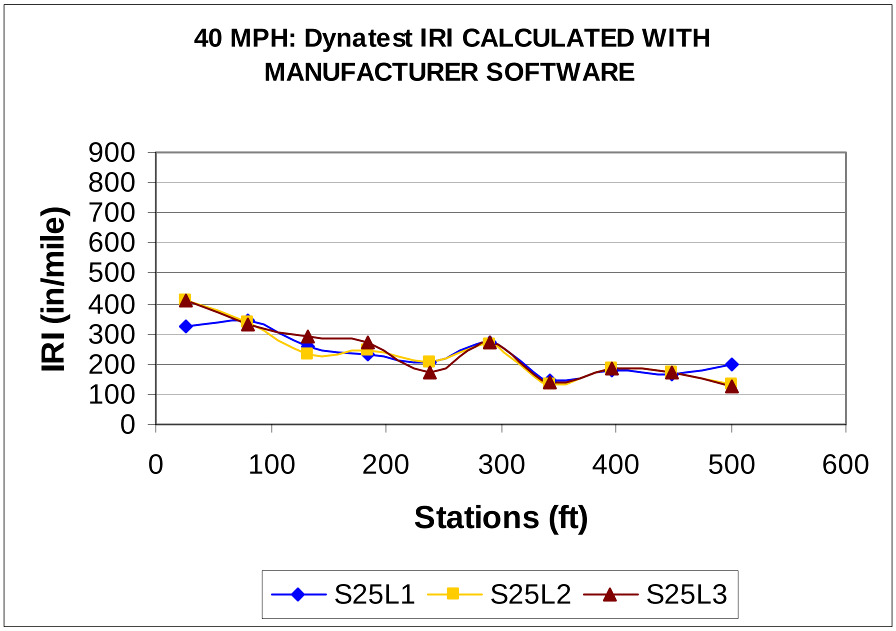


Figure B57: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

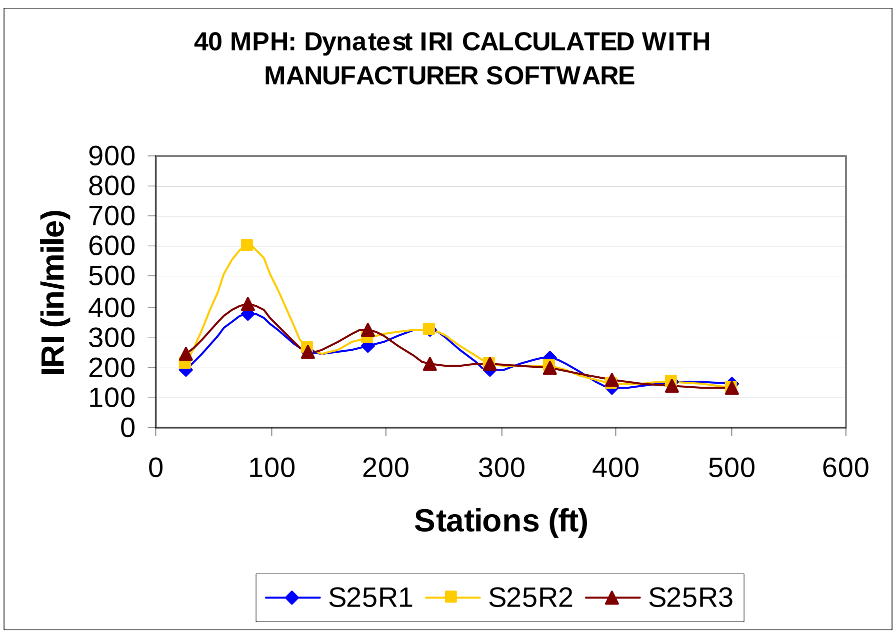


Figure B58: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

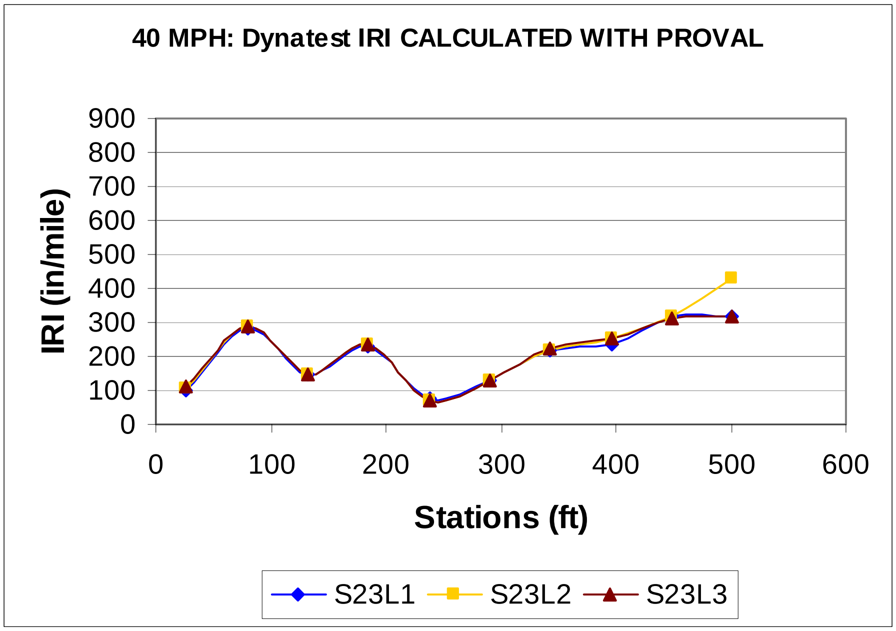


Figure B59: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

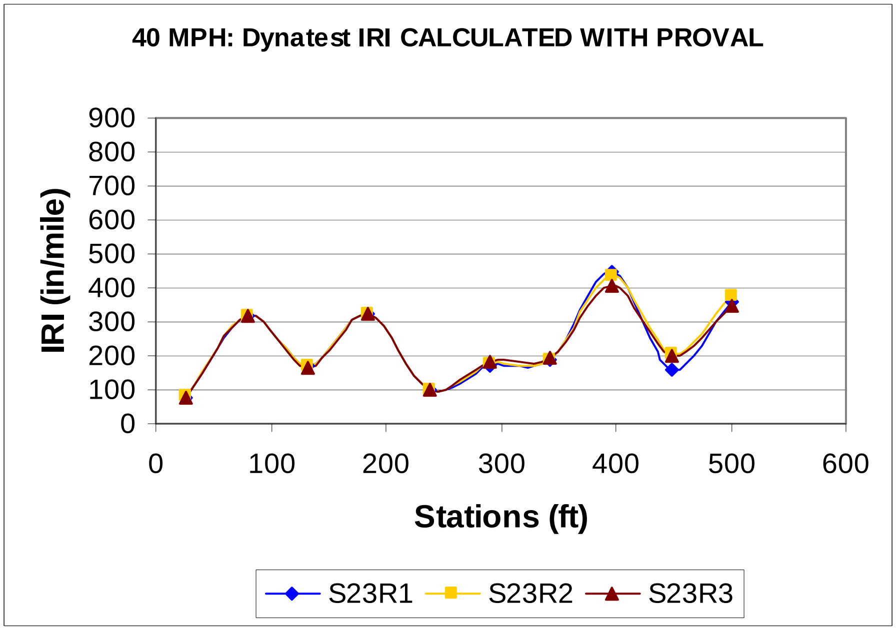


Figure B60: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

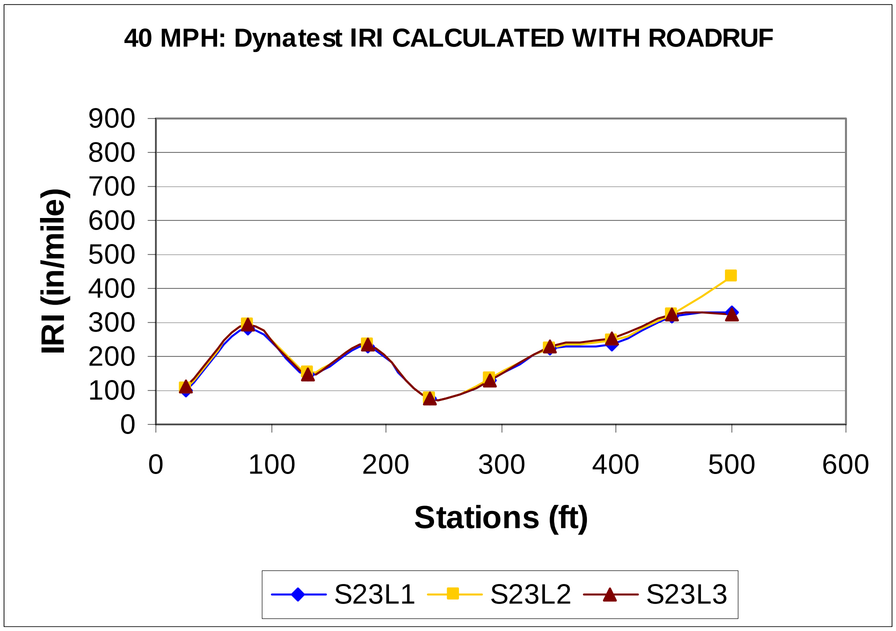


Figure B61: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

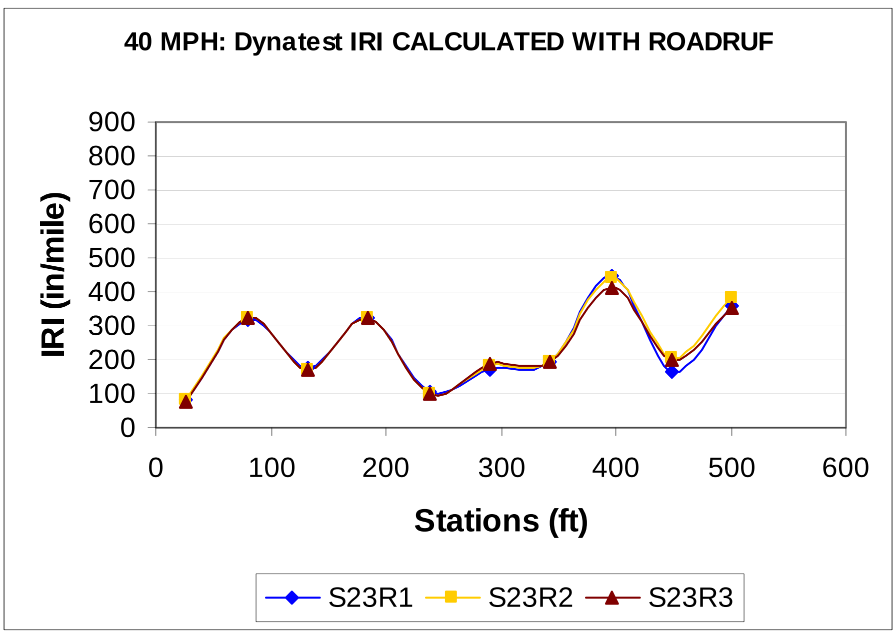


Figure B62: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

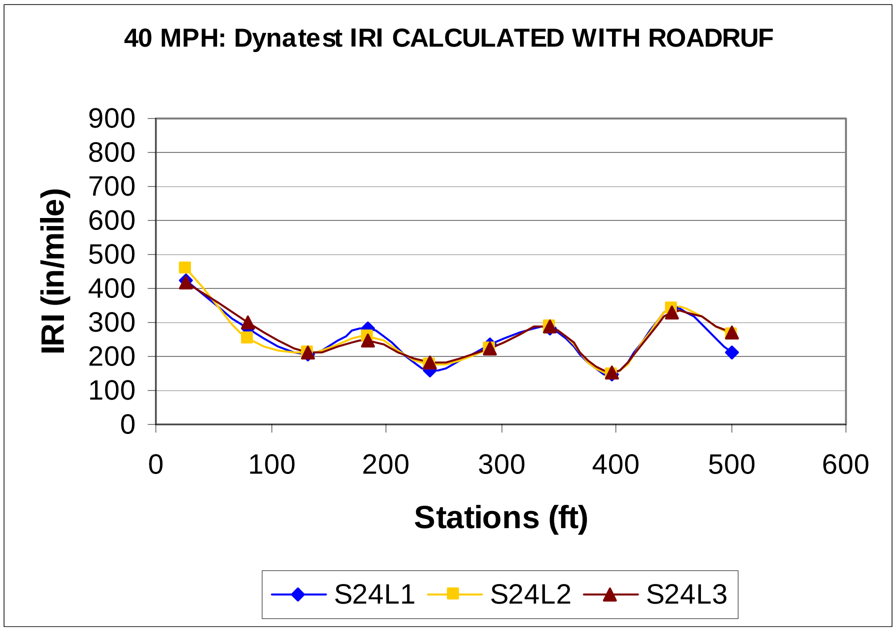


Figure B63: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

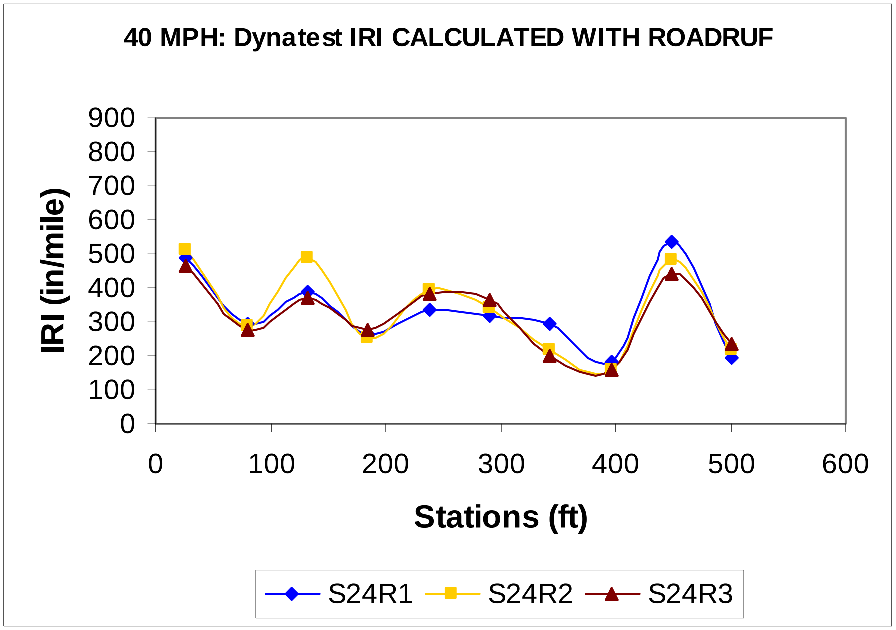


Figure B64: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

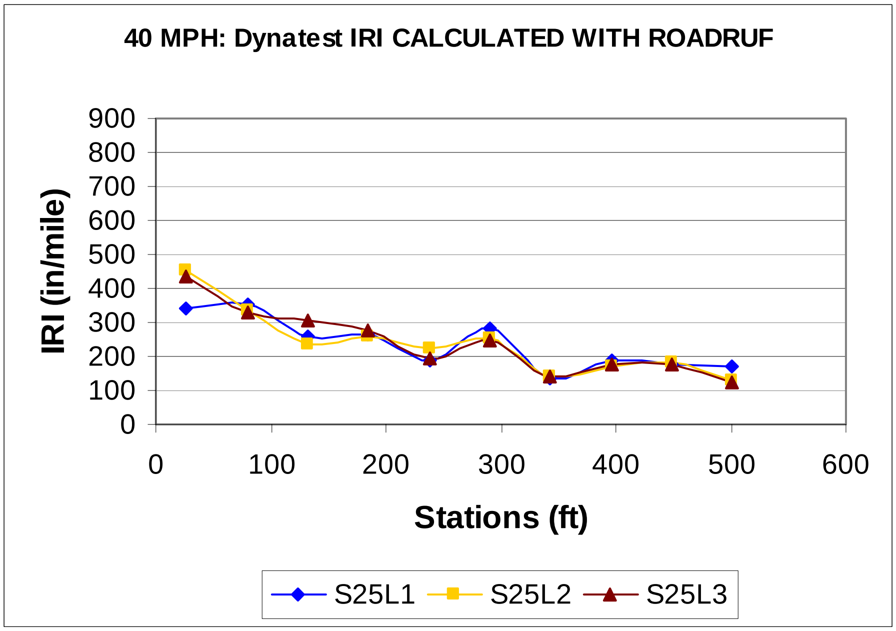


Figure B65: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

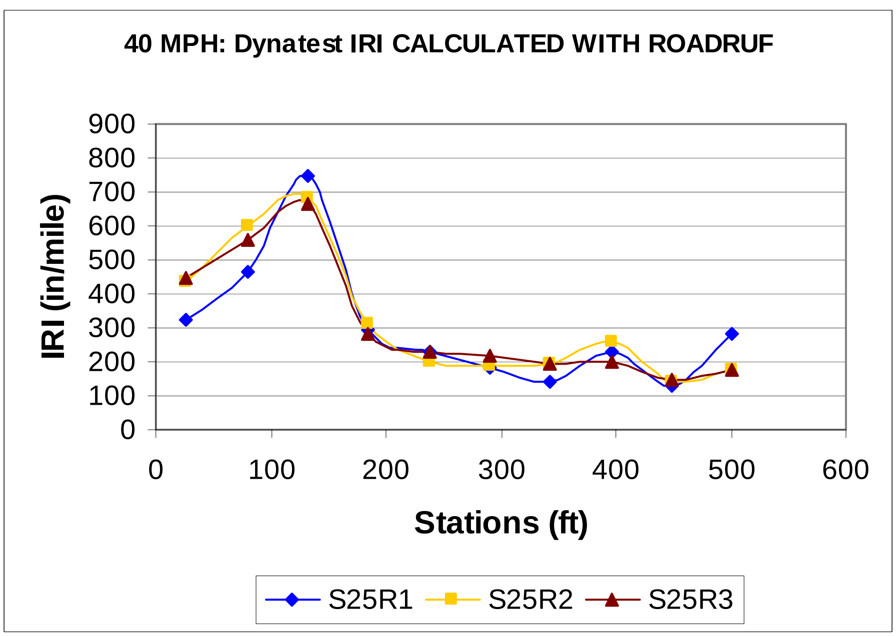


Figure B66: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

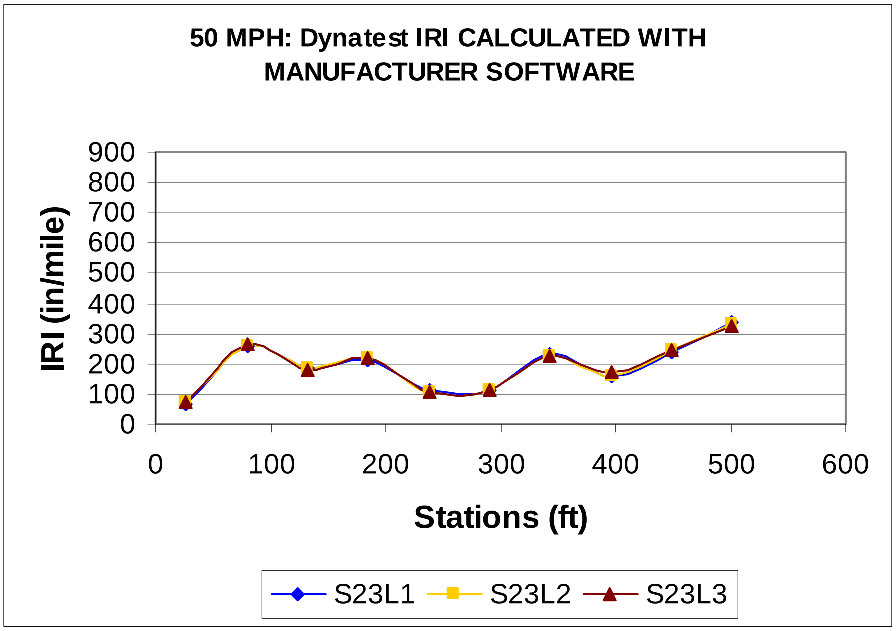


Figure B67: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

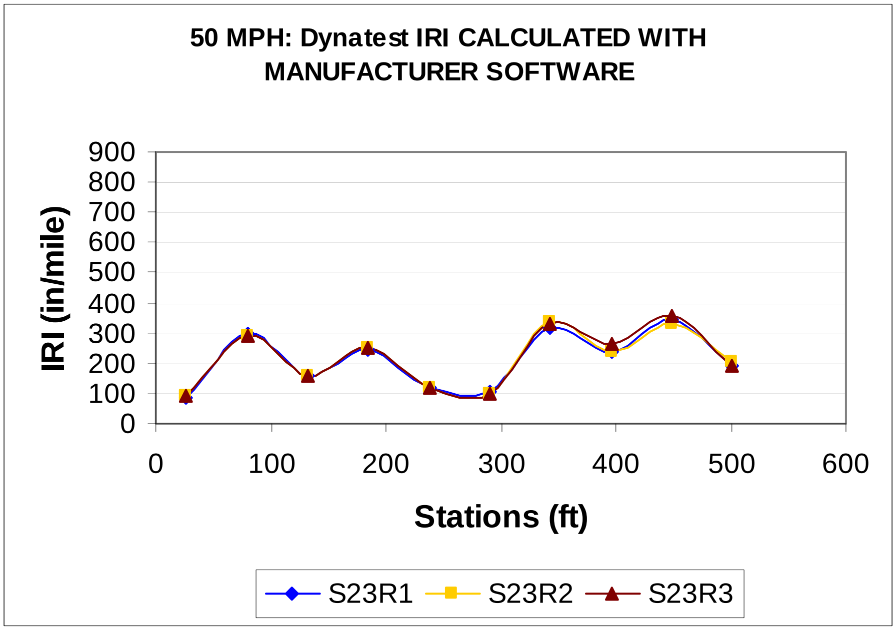


Figure B68: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

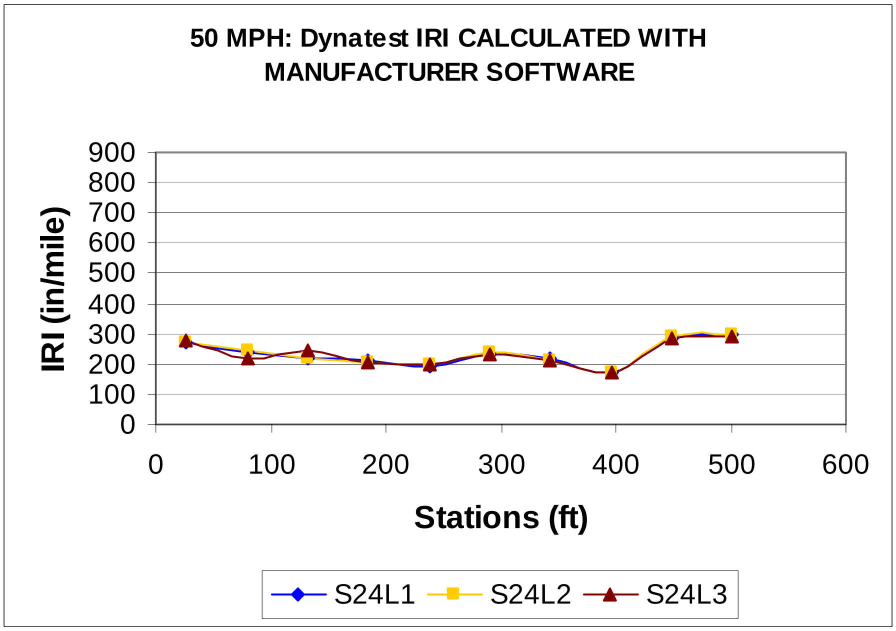


Figure B69: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

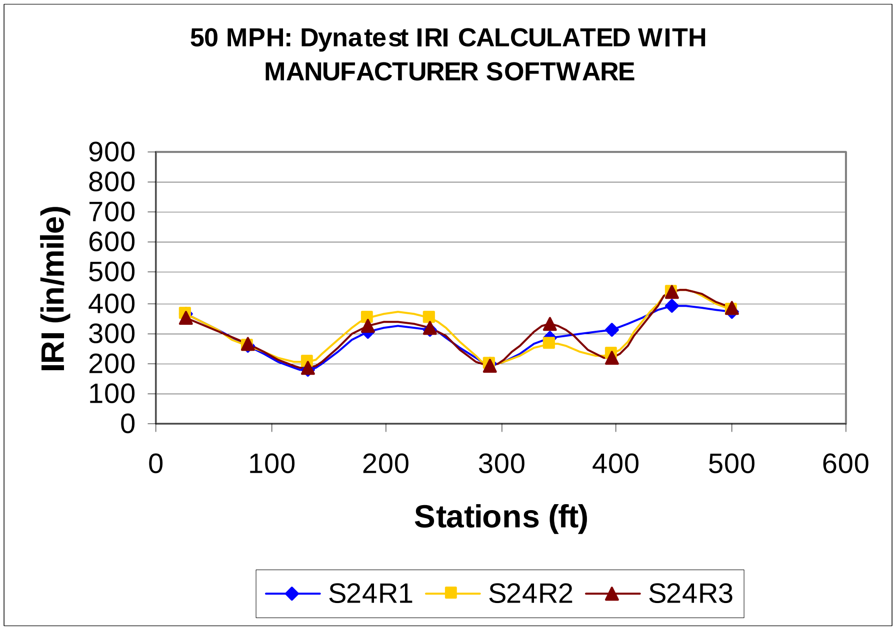


Figure B70: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

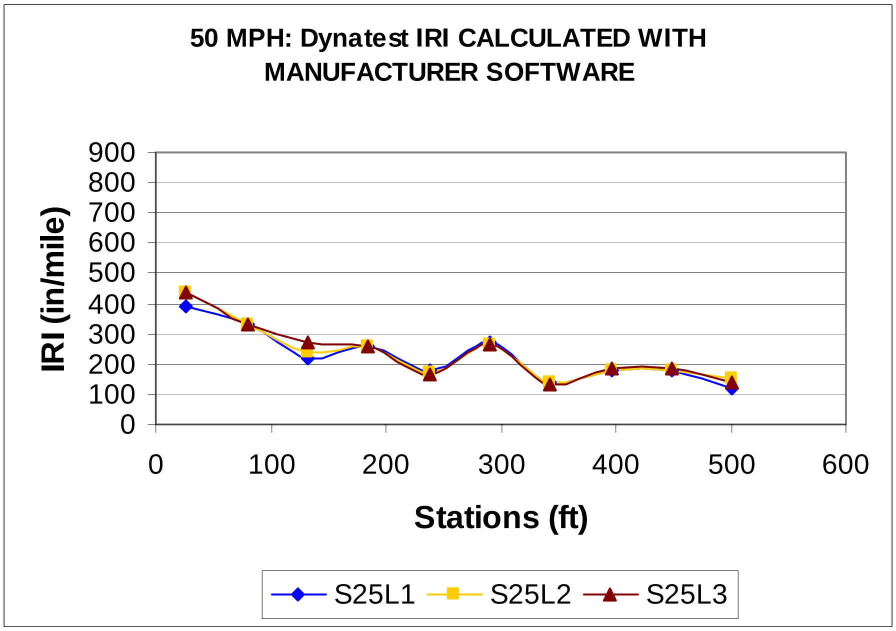


Figure B71: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

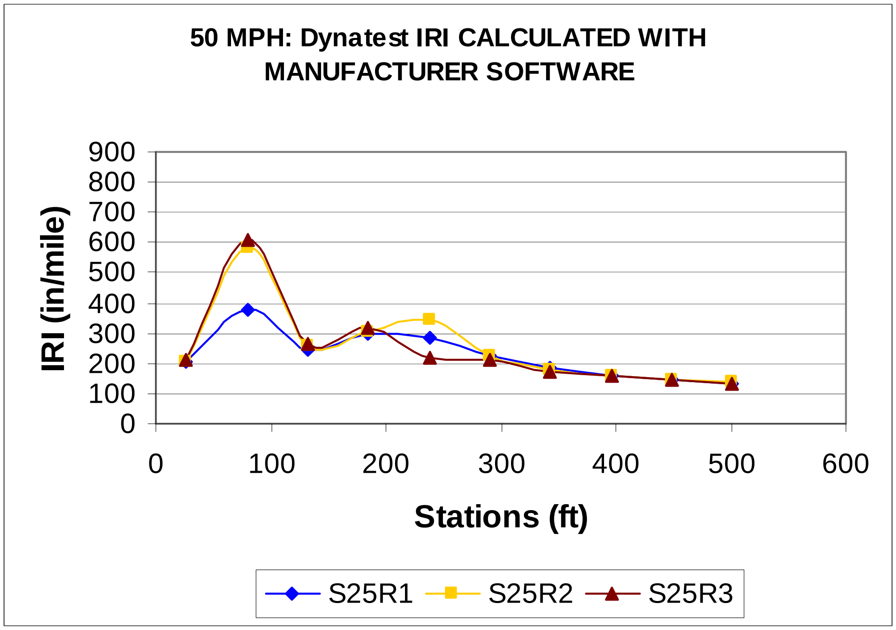


Figure B72: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

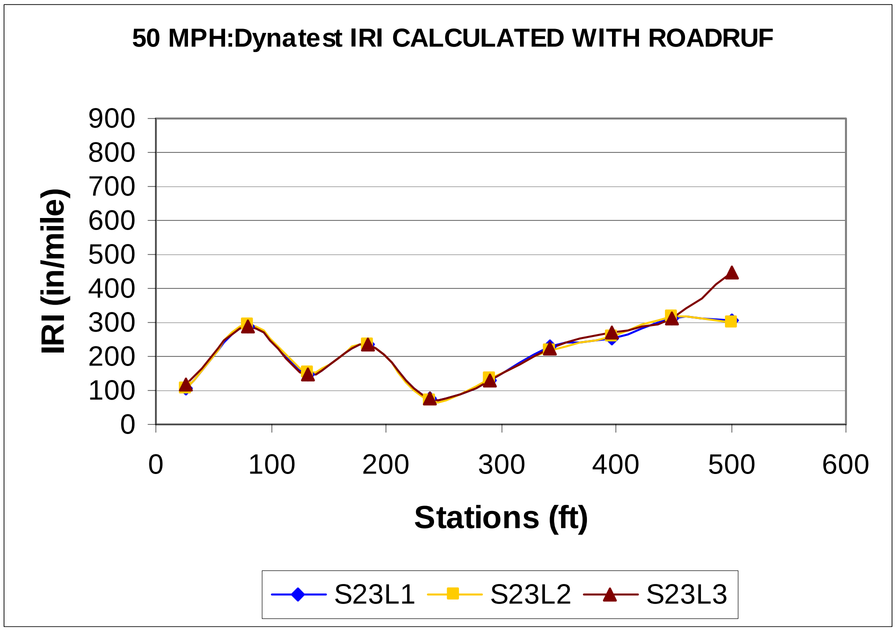


Figure B73: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

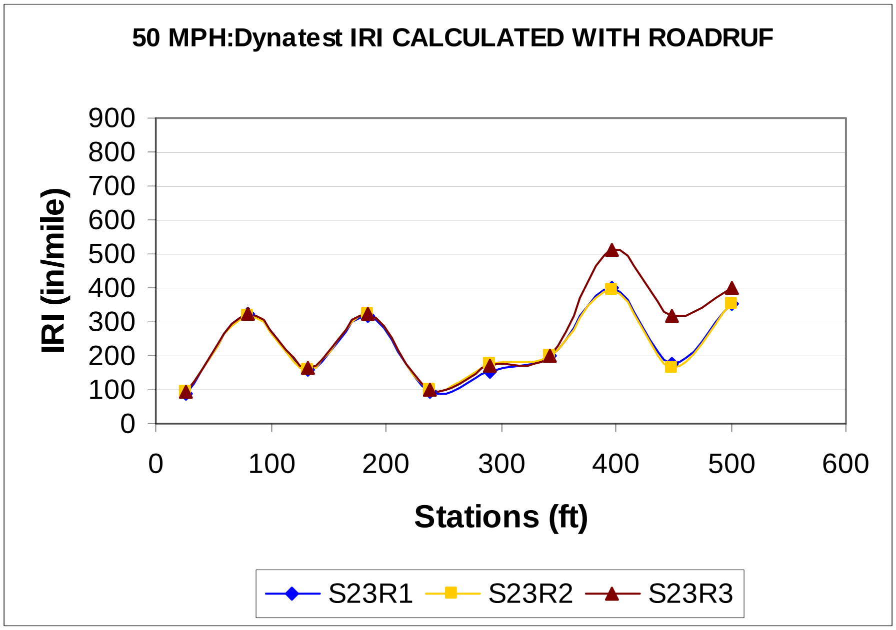


Figure B74: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

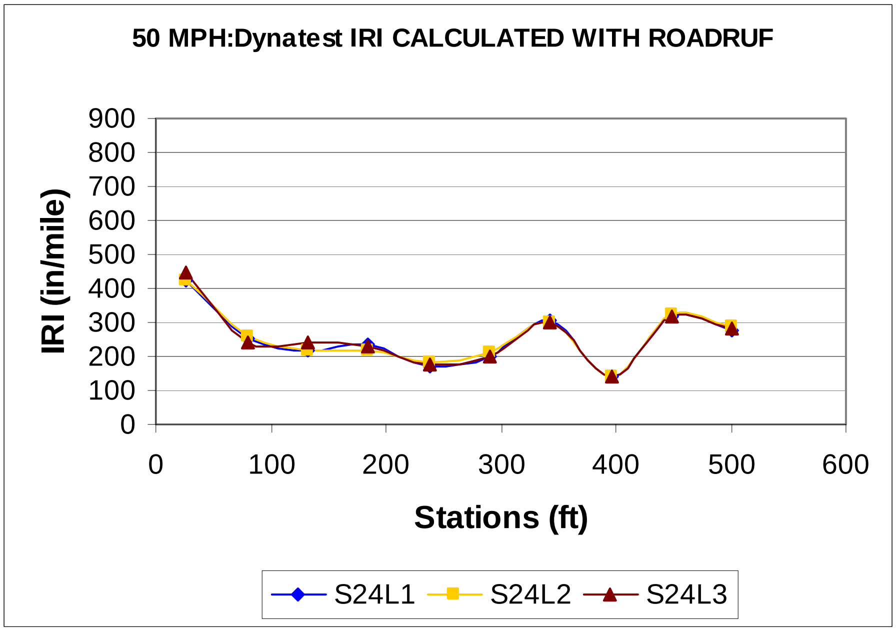


Figure B75: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

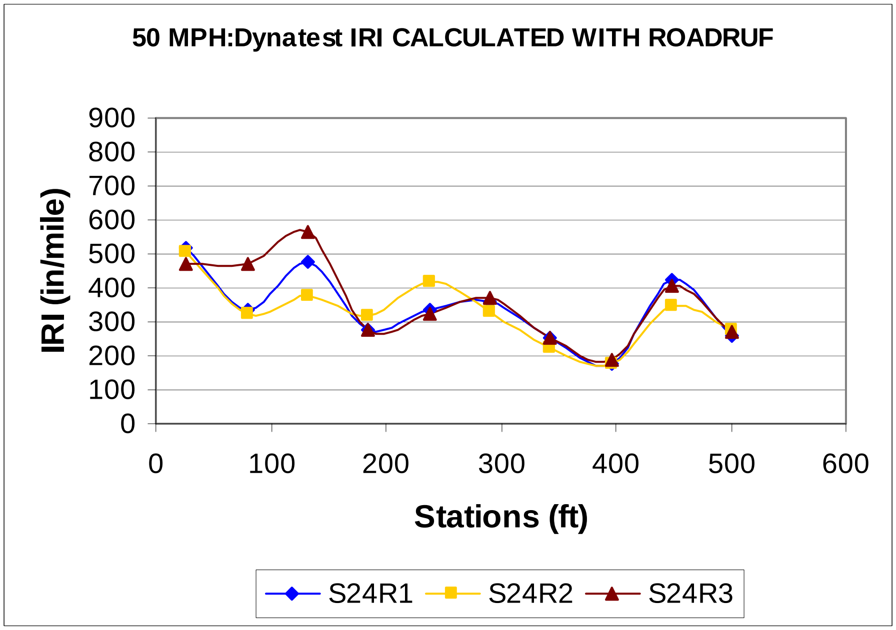


Figure B76: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

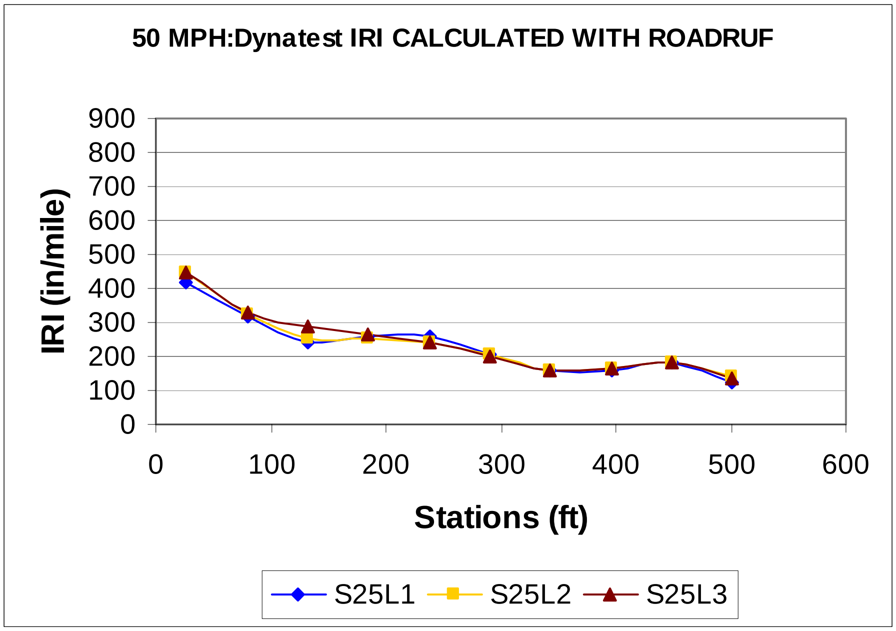


Figure B77: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

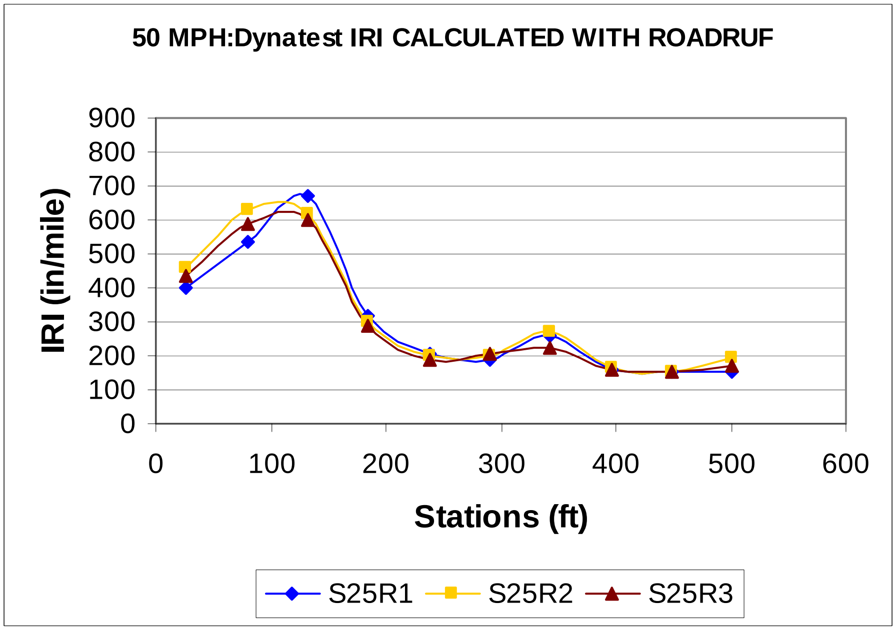


Figure B78: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

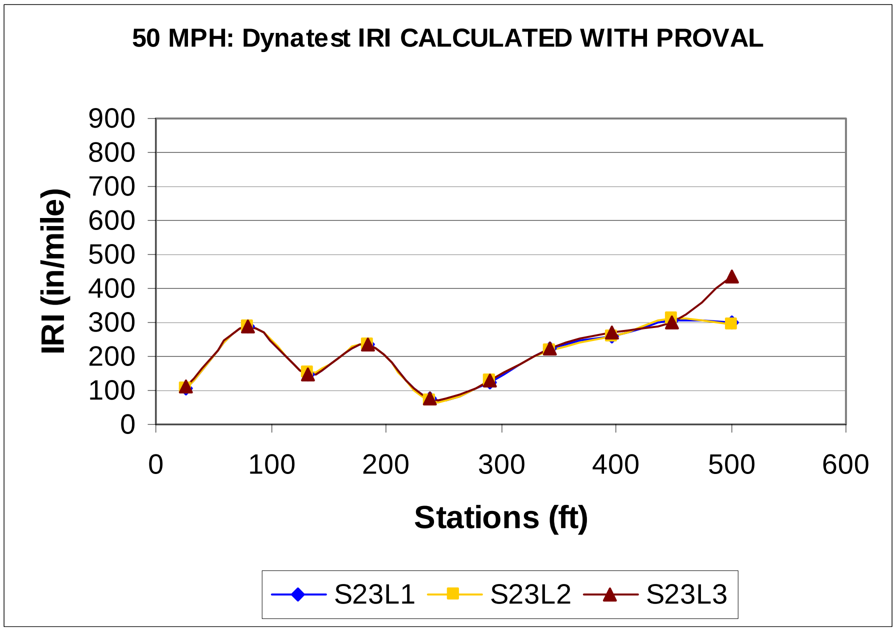


Figure B79: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

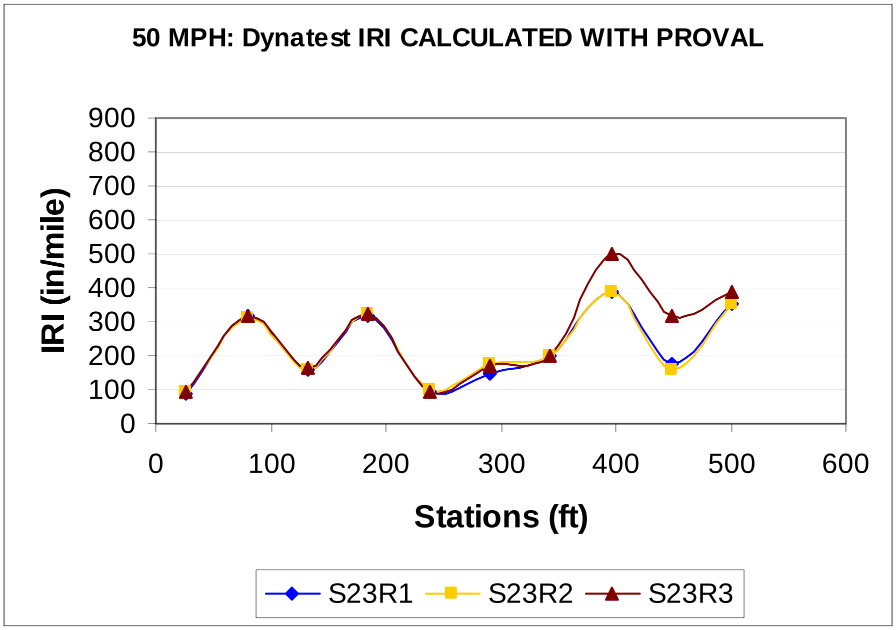


Figure B80: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

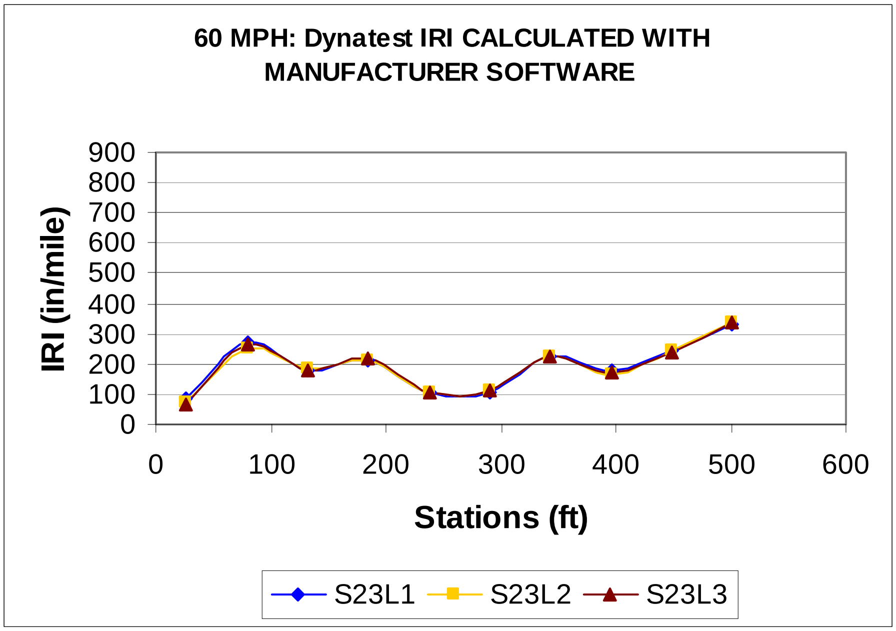


Figure B81: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

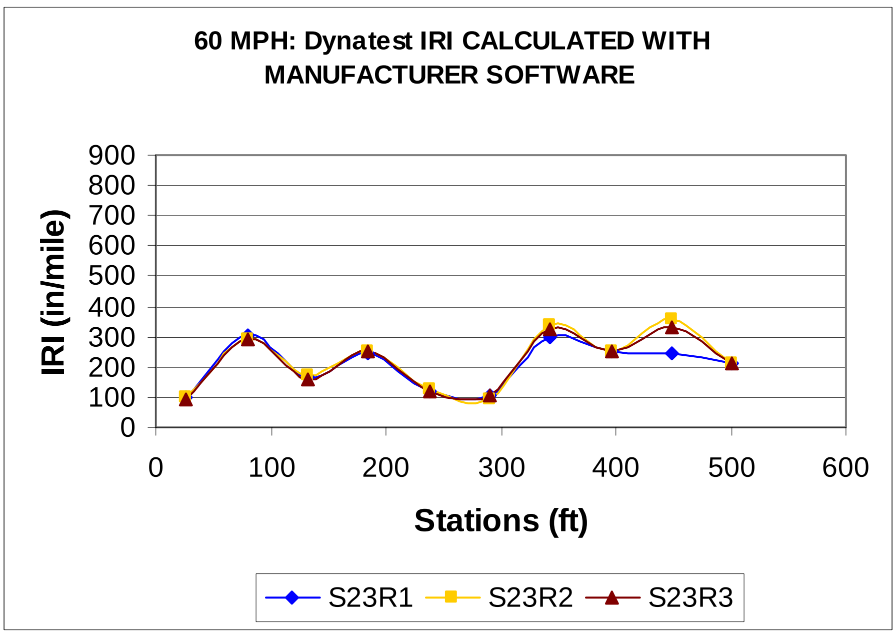


Figure B82: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

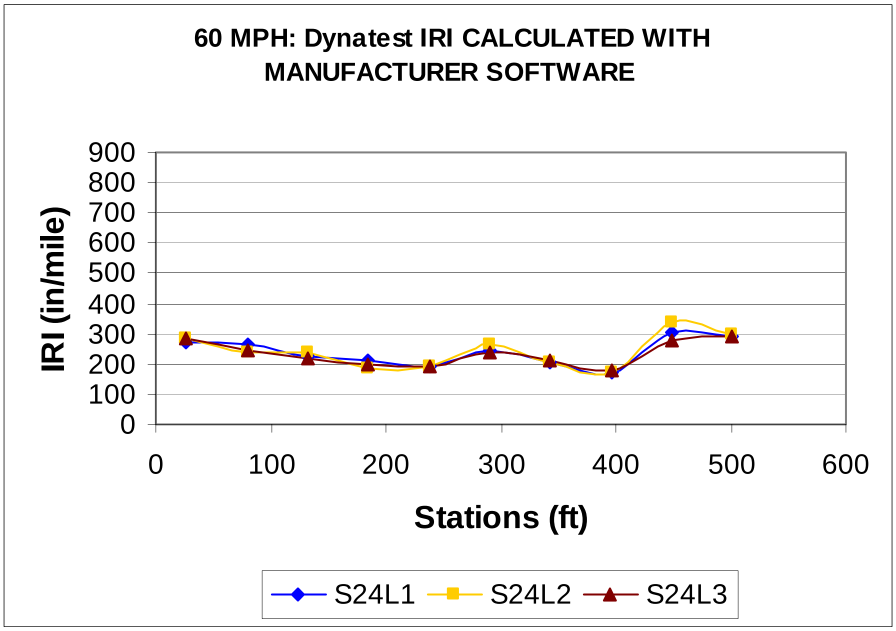


Figure B83: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

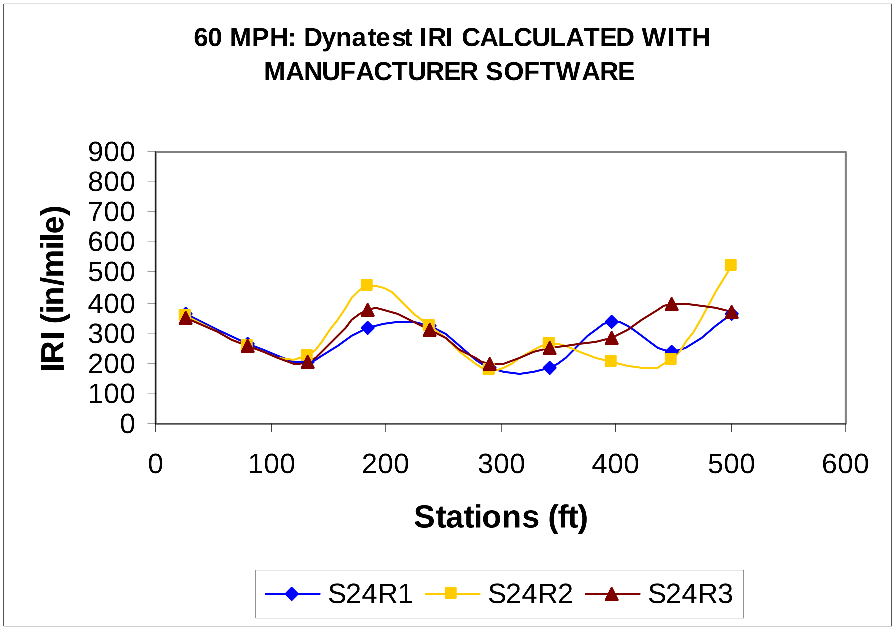


Figure B84: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

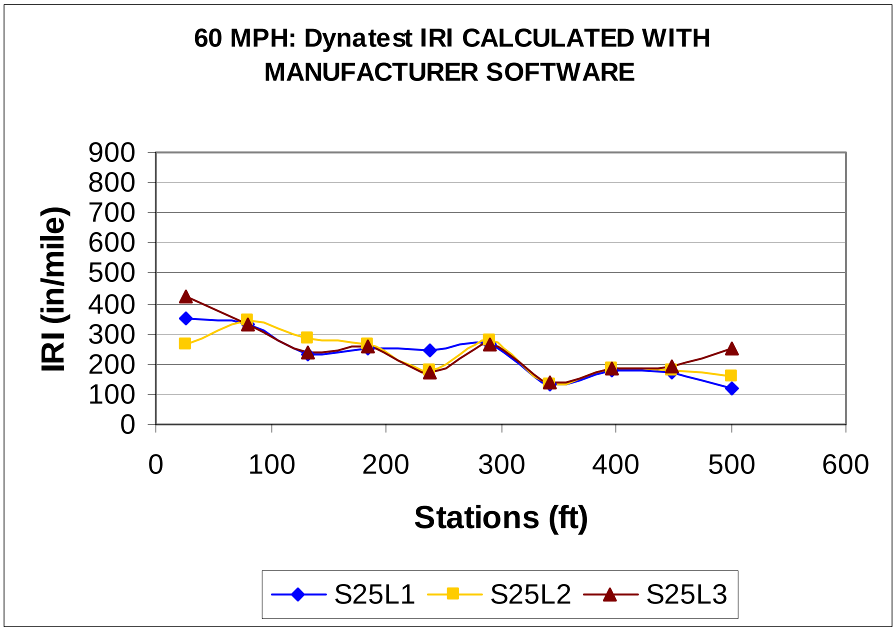


Figure B85: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

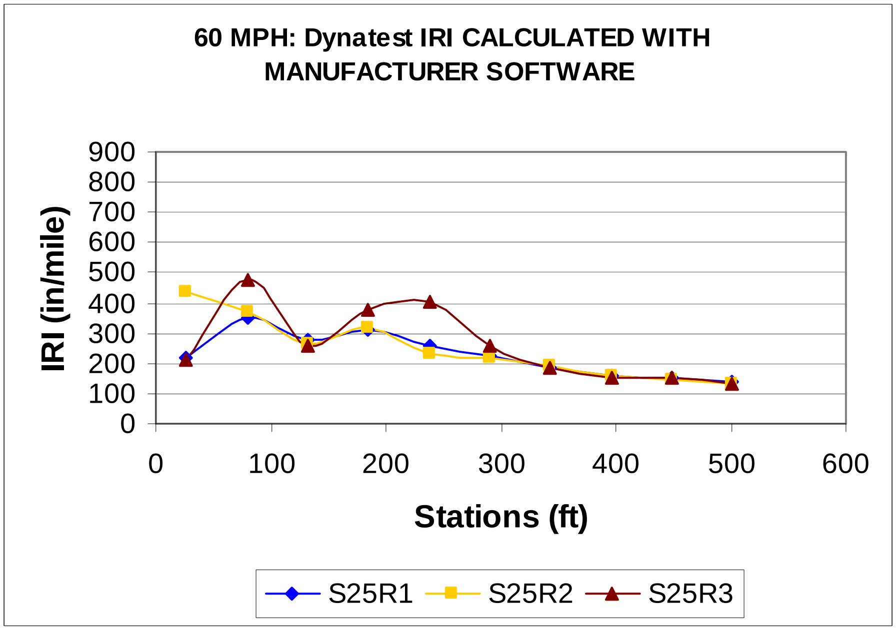


Figure B86: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

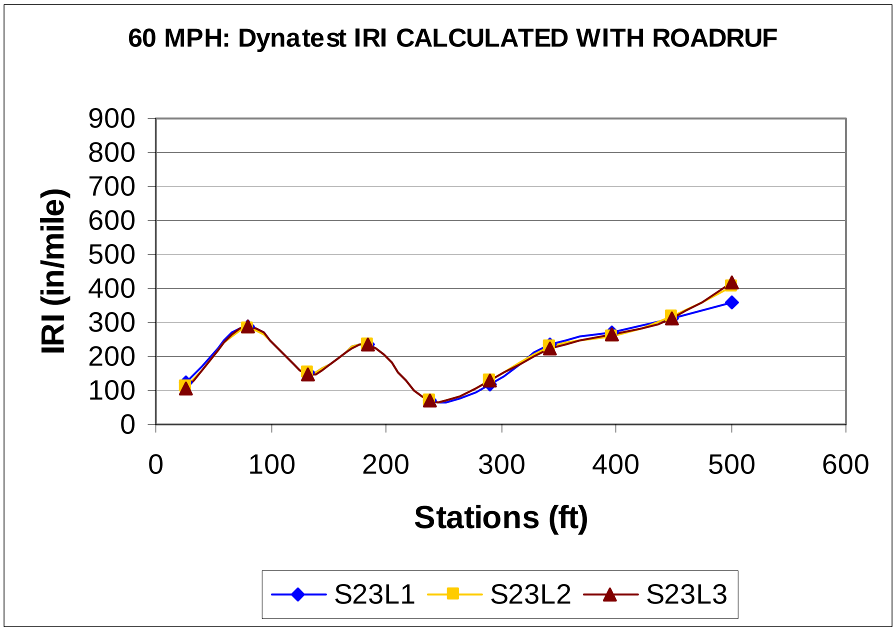


Figure B87: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

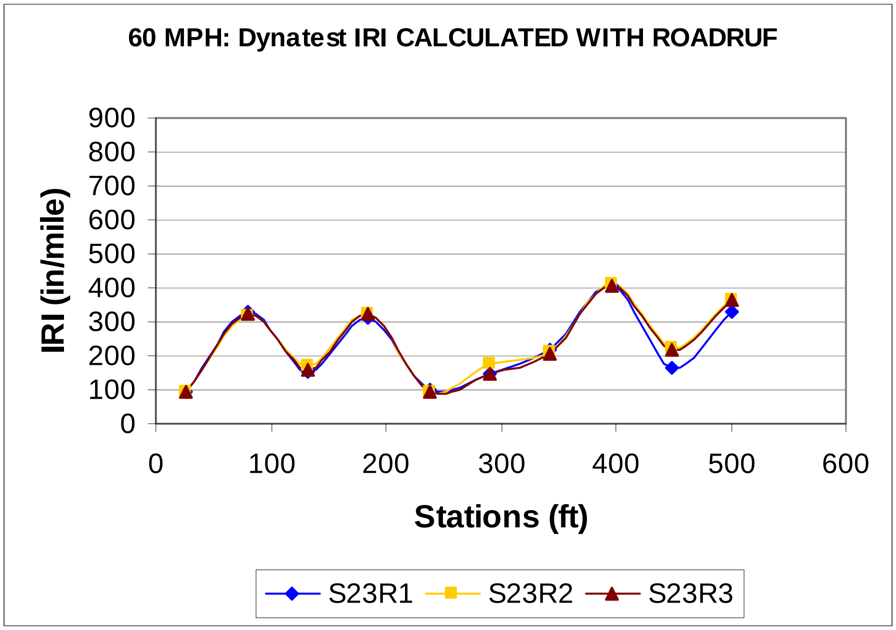


Figure B88: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

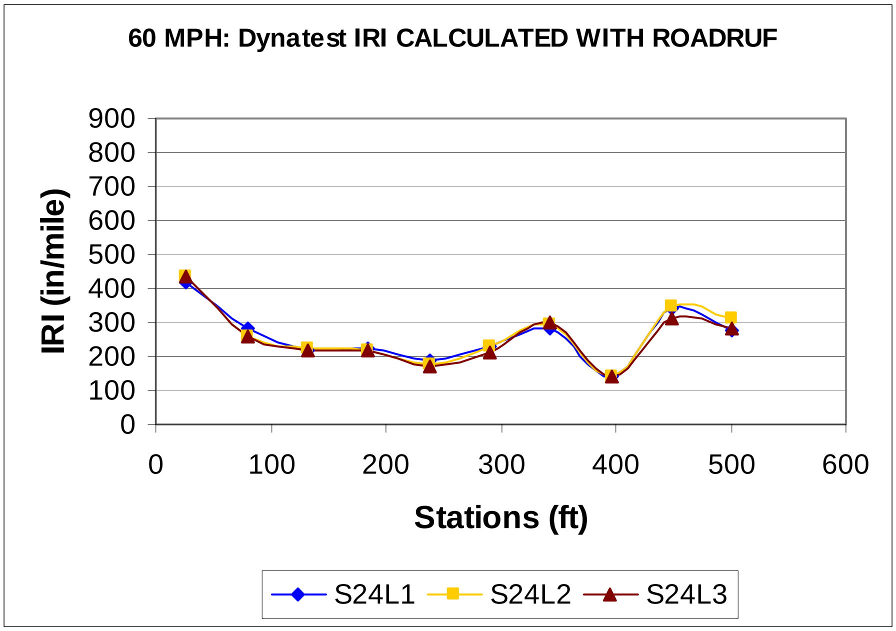


Figure B89: IRI, Route 18, Relatively Rough, Section 24, Left Wheel Path

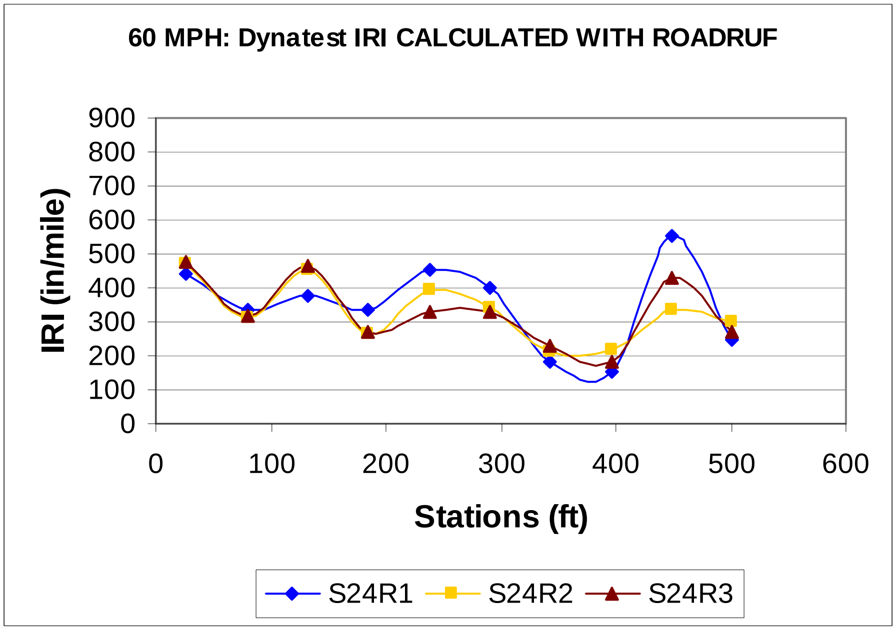


Figure B90: IRI, Route 18, Relatively Rough, Section 24, Right Wheel Path

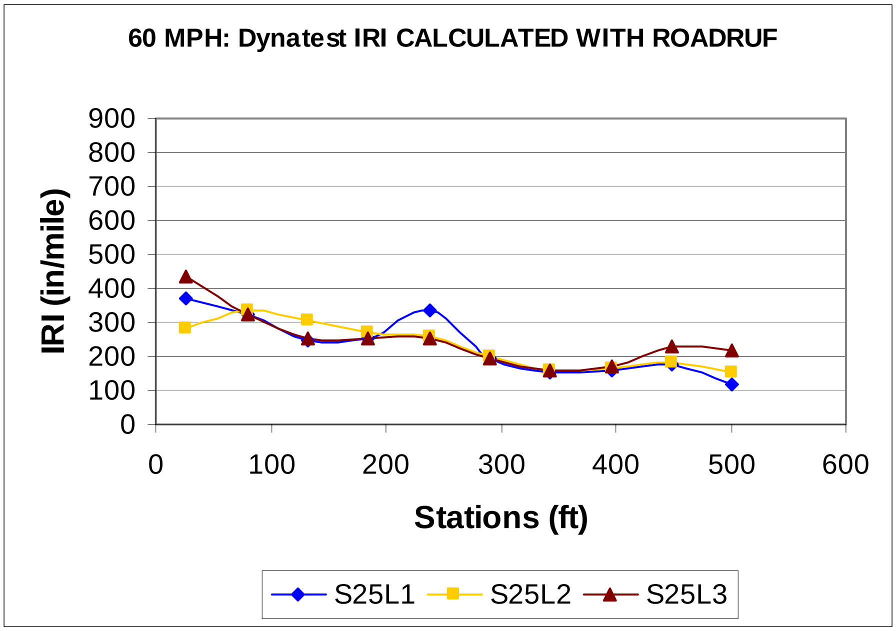


Figure B91: IRI, Route 18, Relatively Rough, Section 25, Left Wheel Path

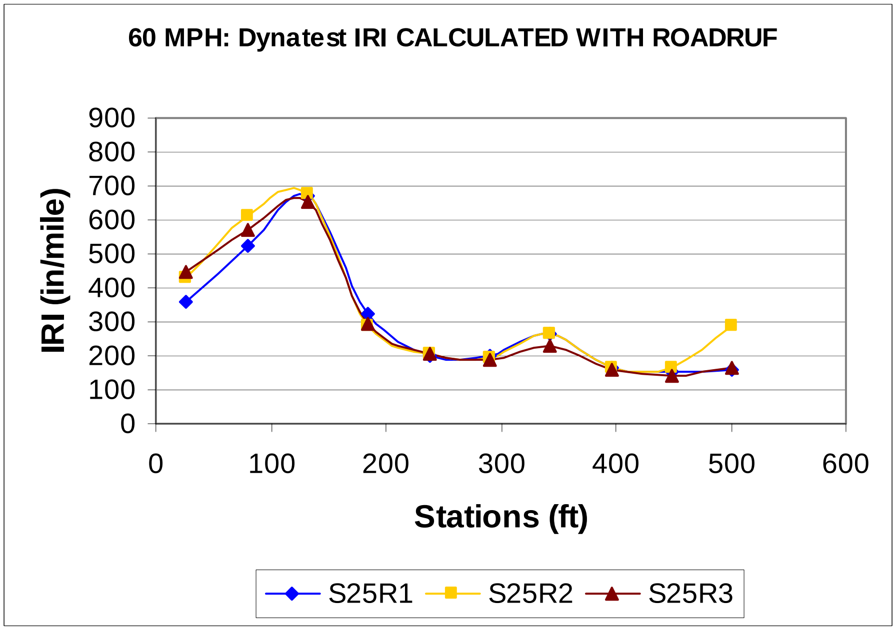


Figure B92: IRI, Route 18, Relatively Rough, Section 25, Right Wheel Path

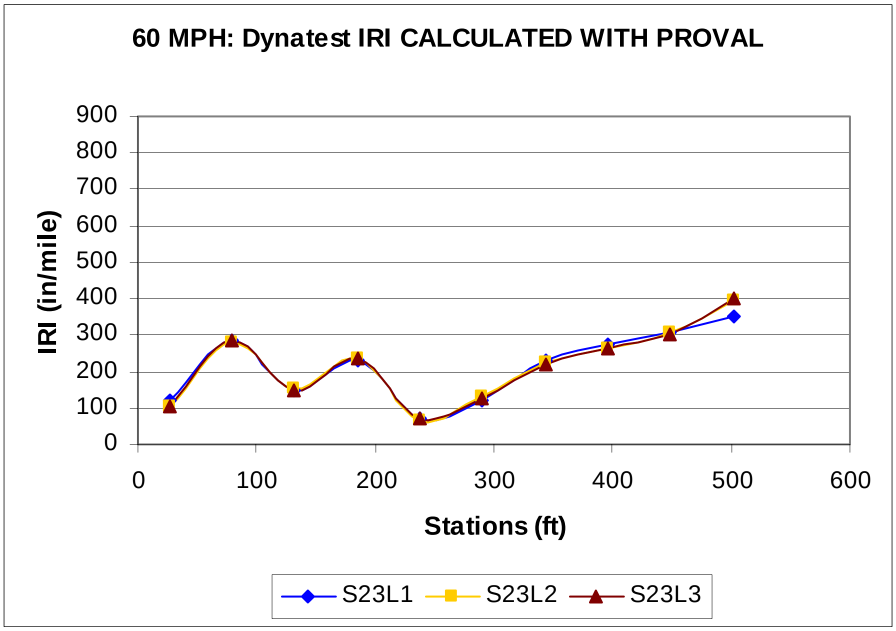


Figure B93: IRI, Route 18, Relatively Rough, Section 23, Left Wheel Path

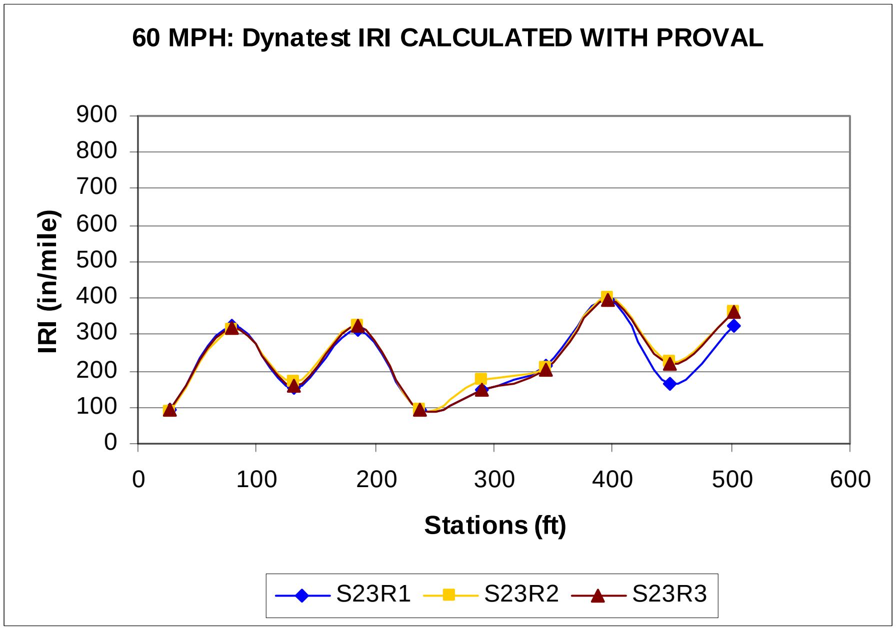


Figure B94: IRI, Route 18, Relatively Rough, Section 23, Right Wheel Path

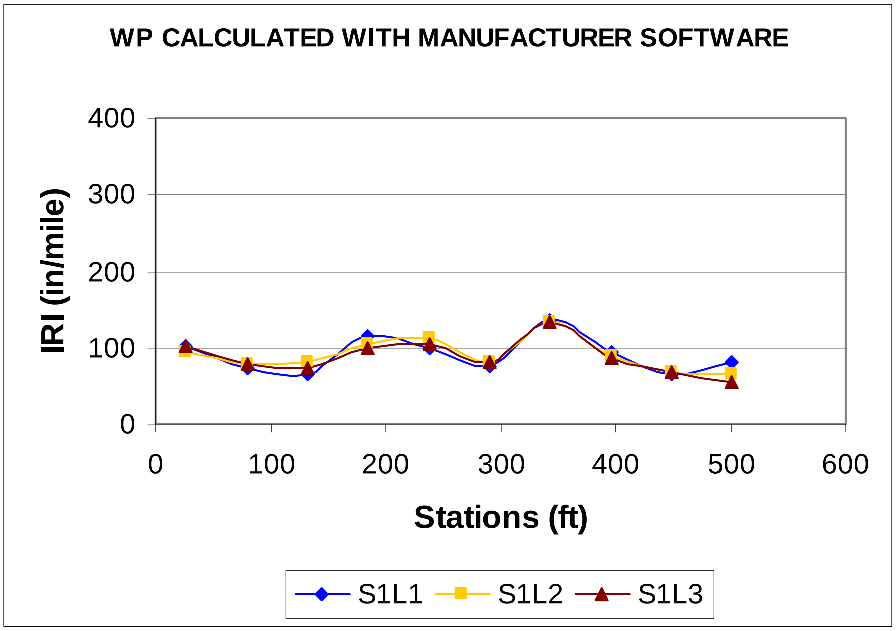


Figure B95: IRI, Route 195, Smooth, Section 1, Left Wheel Path

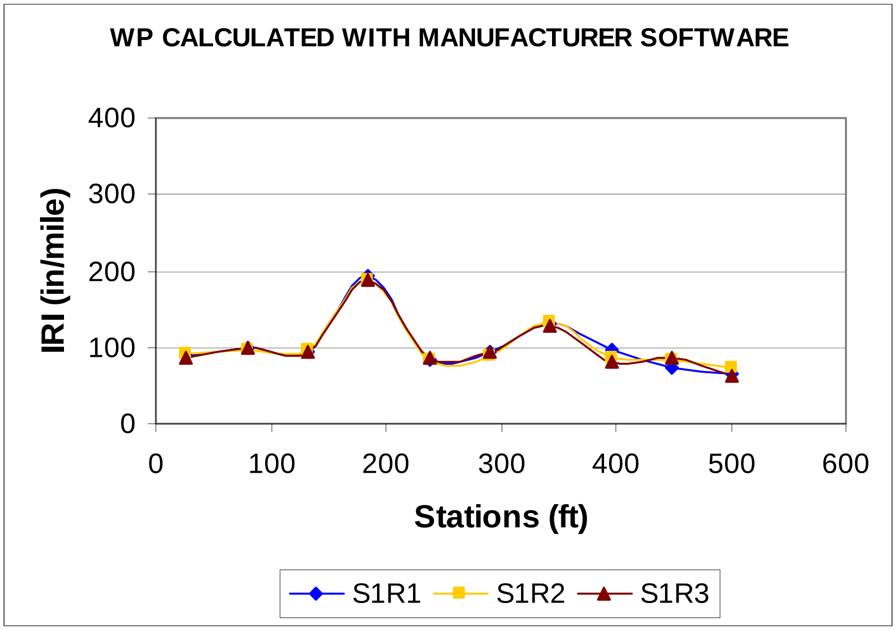


Figure B96: IRI, Route 195, Smooth, Section 1, Right Wheel Path

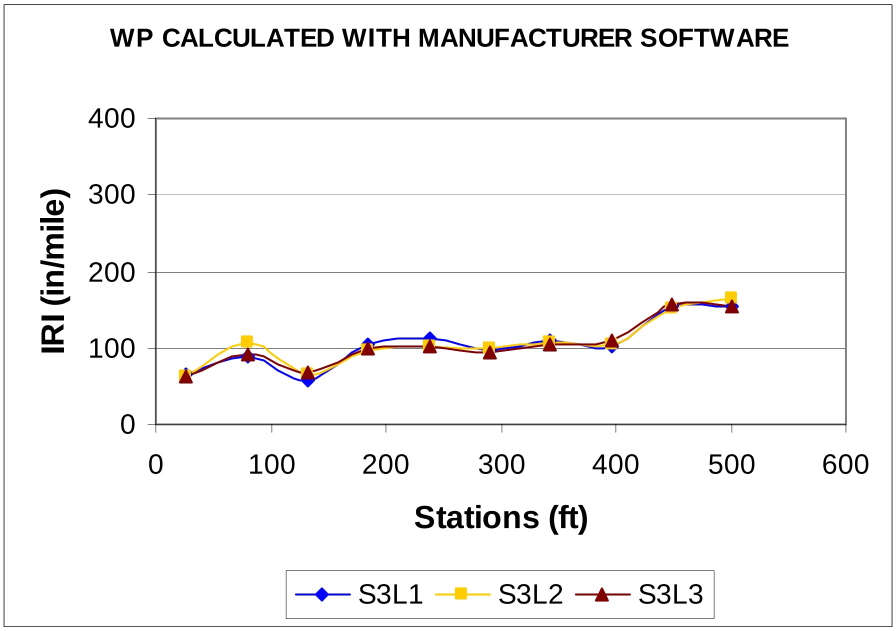


Figure B97: IRI, Route 195, Smooth, Section 3, Left Wheel Path

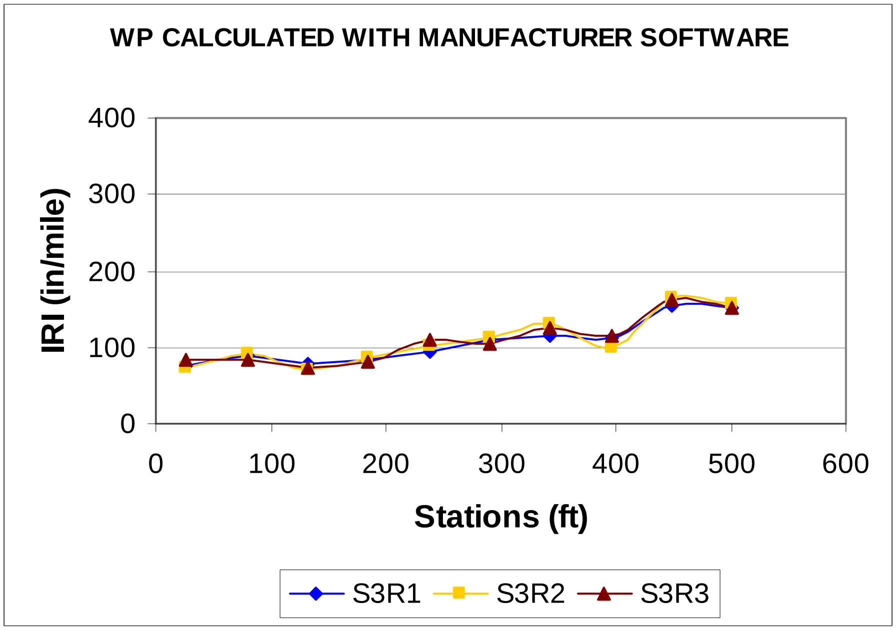


Figure B98: IRI, Route 195, Smooth, Section 3, Right Wheel Path

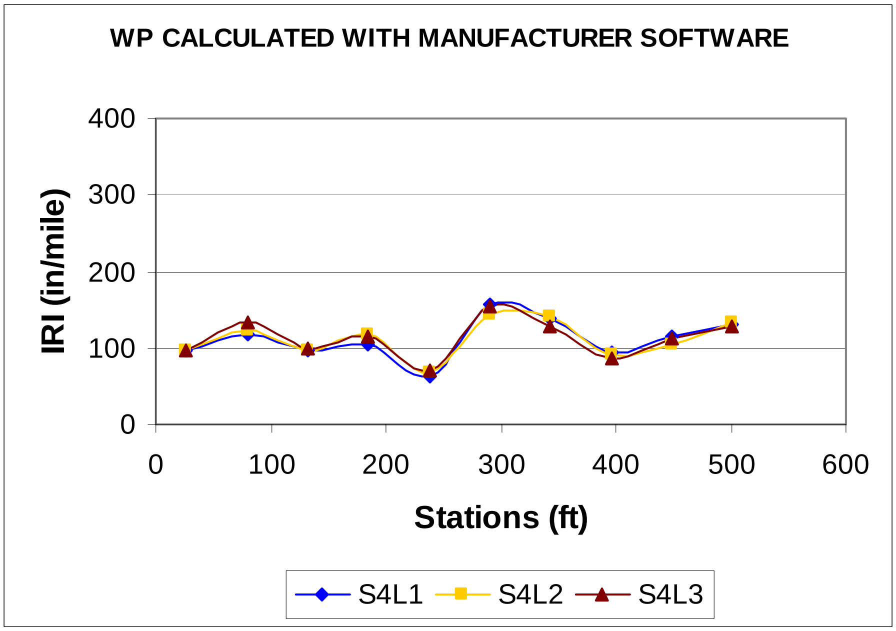


Figure B99: IRI, Route 195, Smooth, Section 4, Left Wheel Path

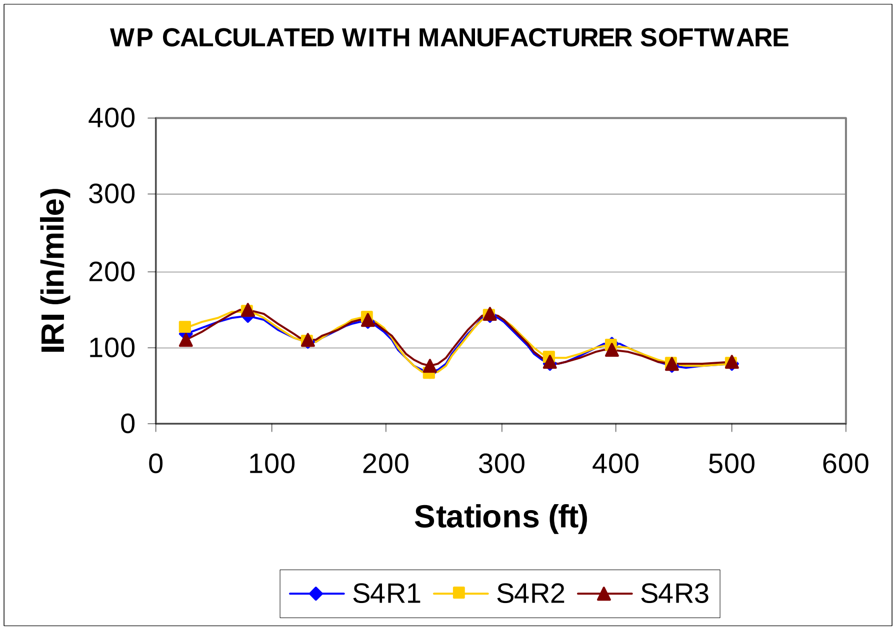


Figure B100: IRI, Route 195, Smooth, Section 4, Right Wheel Path

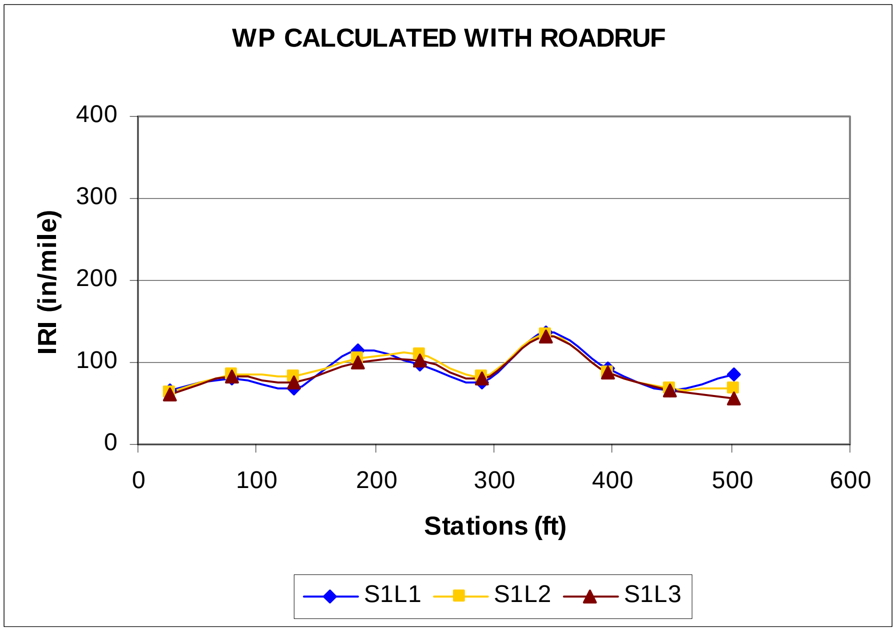


Figure B101: IRI, Route 195, Smooth, Section 1, Left Wheel Path

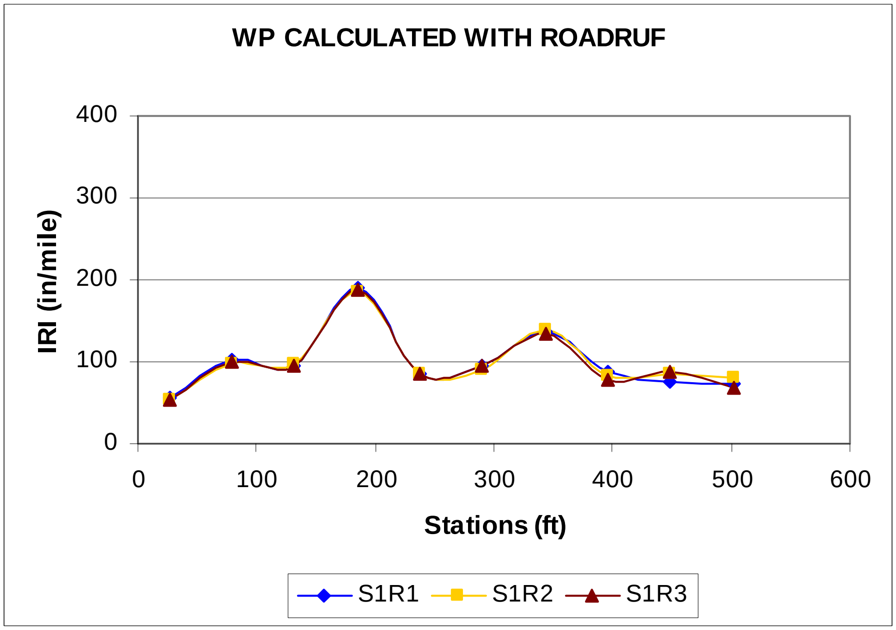


Figure B102: IRI, Route 195, Smooth, Section 1, Right Wheel Path

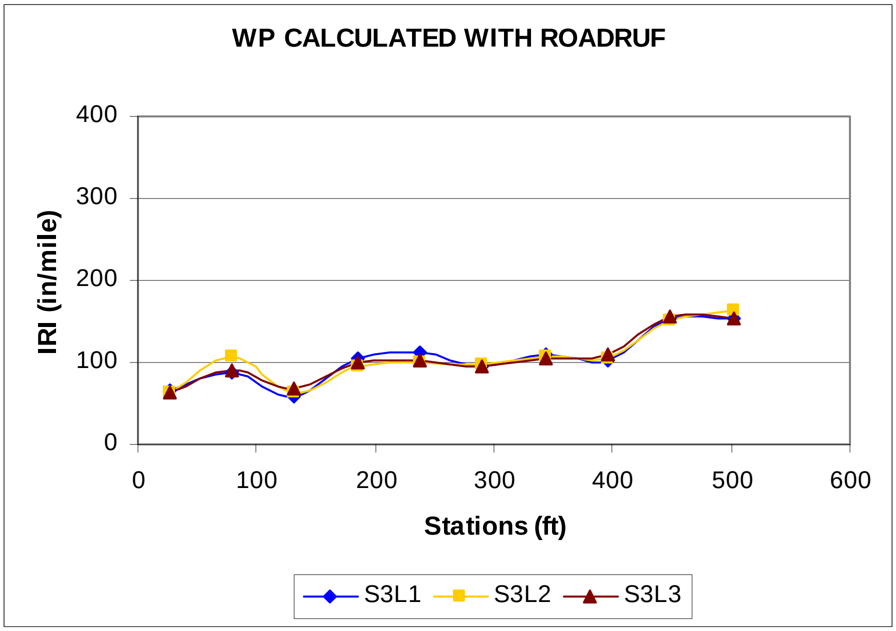


Figure B103: IRI, Route 195, Smooth, Section 3, Left Wheel Path

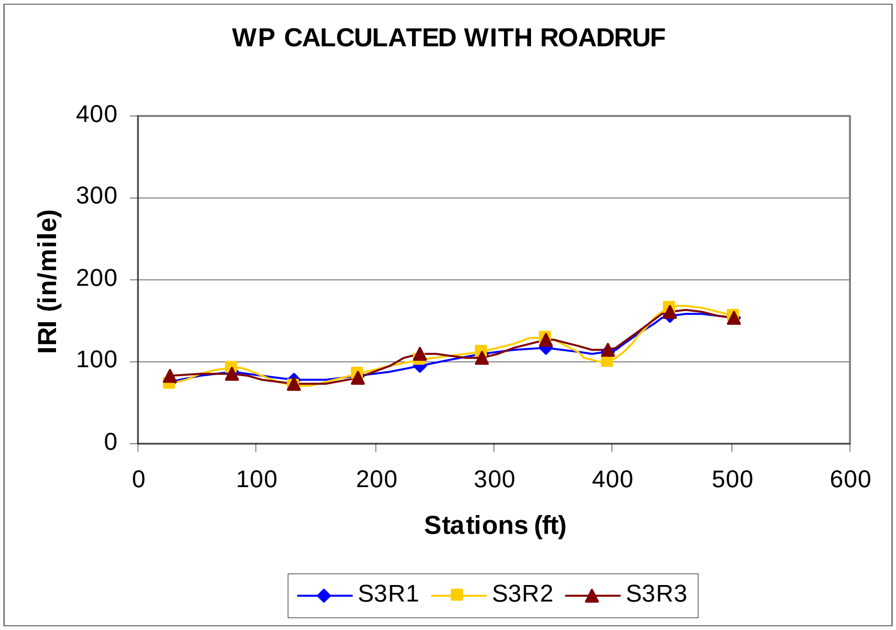


Figure B104: IRI, Route 195, Smooth, Section 3, Right Wheel Path

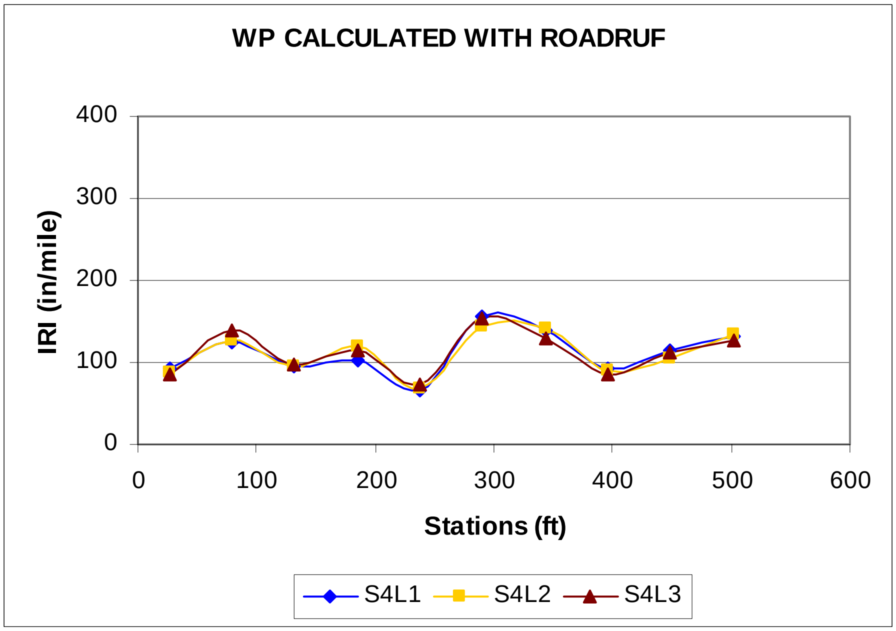


Figure B105: IRI, Route 195, Smooth, Section 4, Left Wheel Path

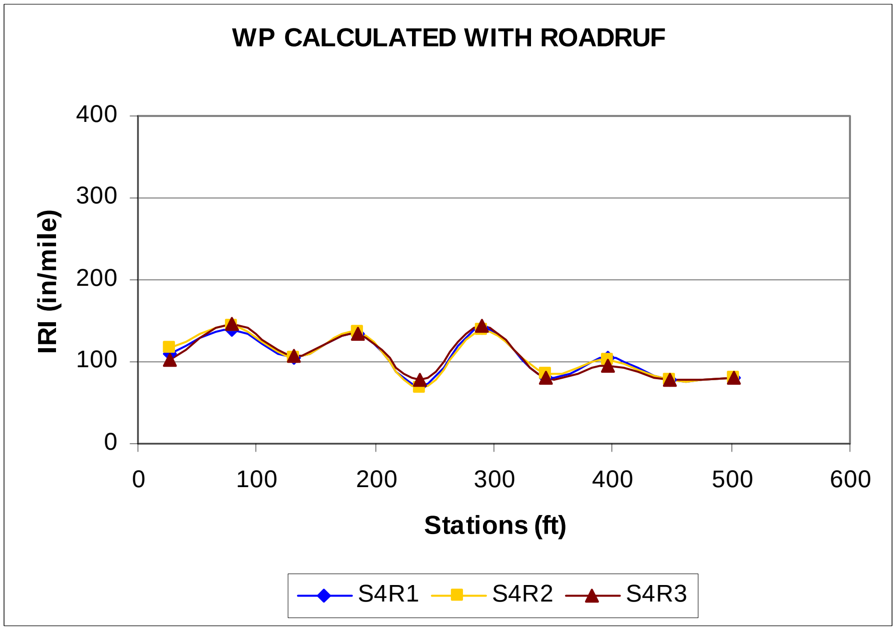


Figure B106: IRI, Route 195, Smooth, Section 4, Right Wheel Path

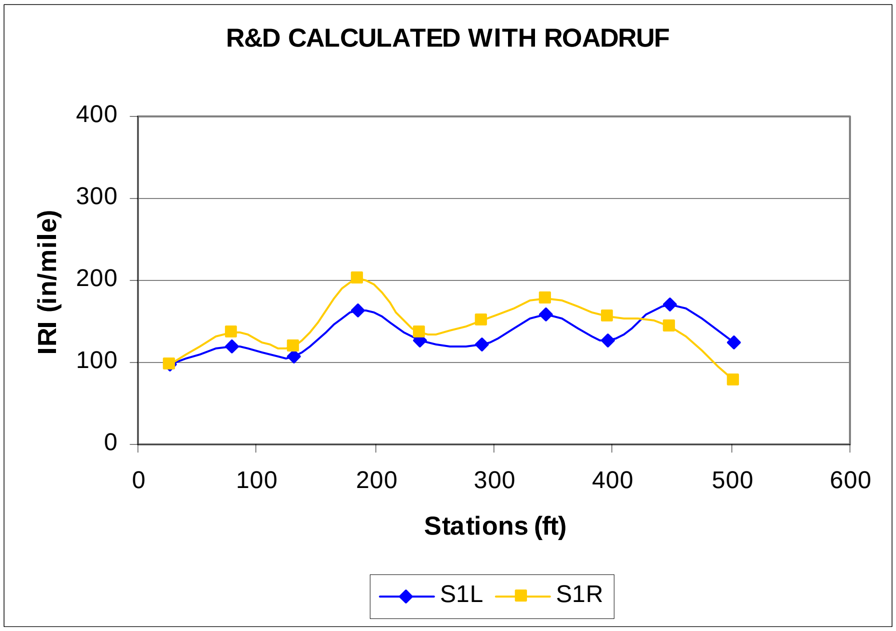


Figure B107: IRI, Route 195, Smooth, Section 1, Left and Right Wheel Path

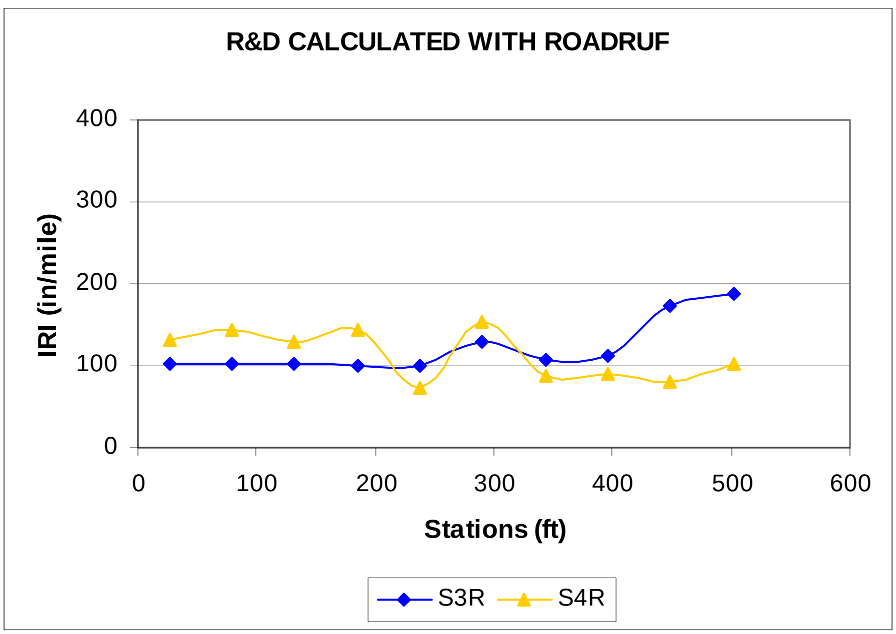


Figure B108: IRI, Route 195, Smooth, Section 3 and 4, Right Wheel Path

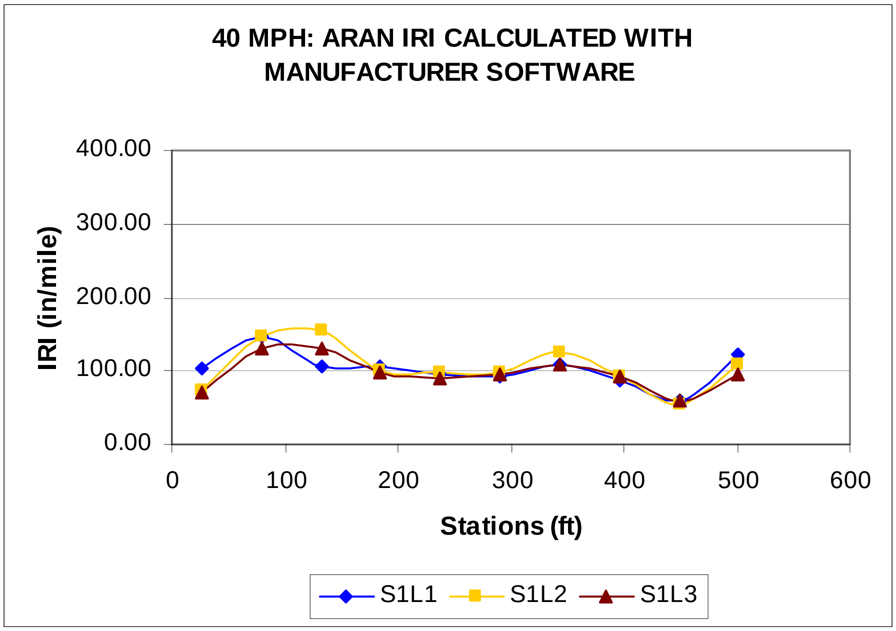


Figure B109: IRI, Route 195, Smooth, Section 1, Left Wheel Path

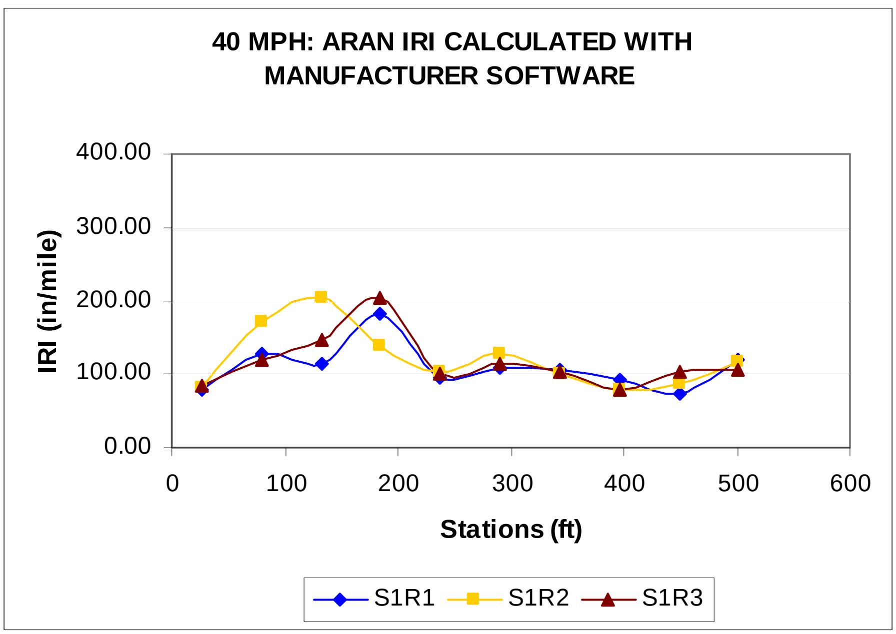


Figure B110: IRI, Route 195, Smooth, Section 1, Right Wheel Path

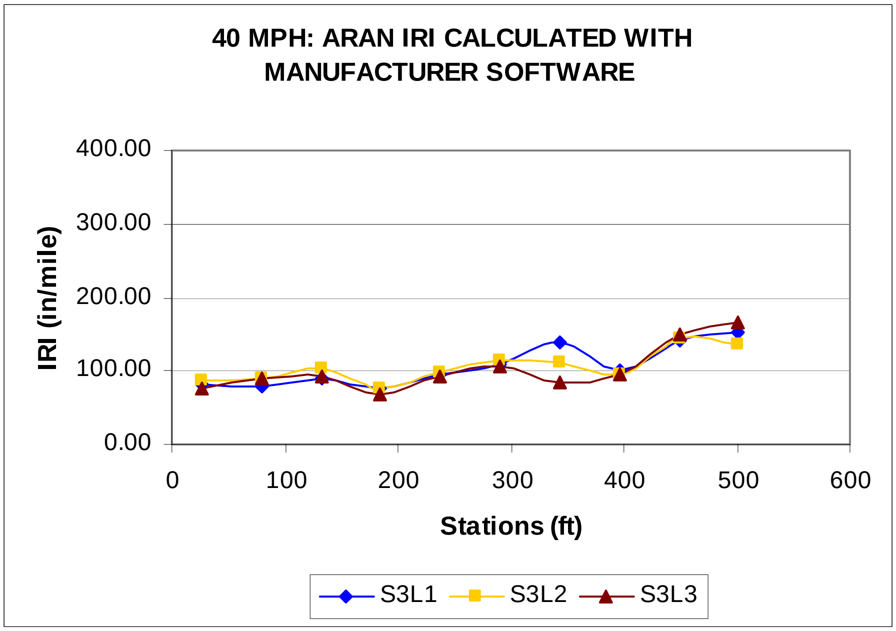


Figure B111: IRI, Route 195, Smooth, Section 3, Left Wheel Path

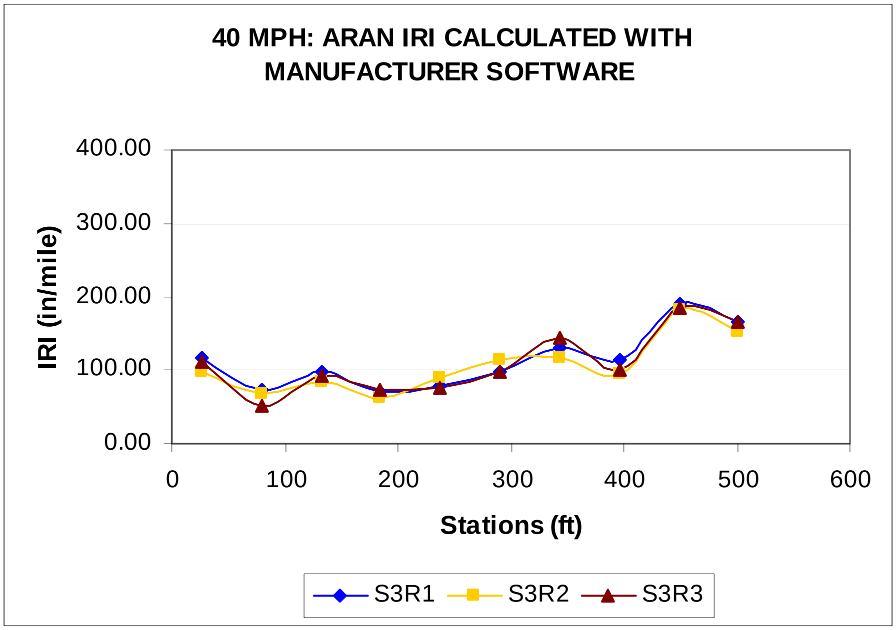


Figure B112: IRI, Route 195, Smooth, Section 3, Right Wheel Path

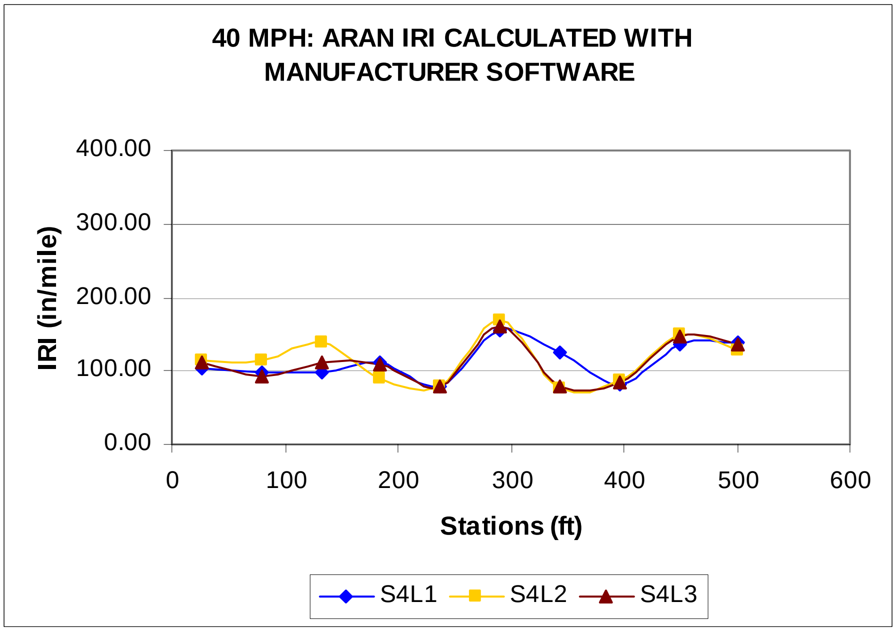


Figure B113: IRI, Route 195, Smooth, Section 4, Left Wheel Path

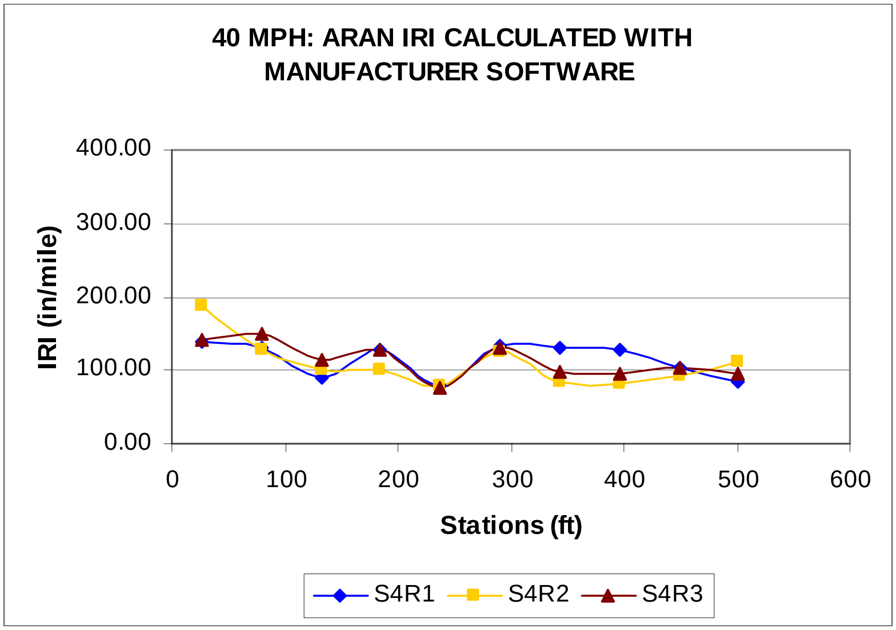


Figure B114: IRI, Route 195, Smooth, Section 4, Right Wheel Path

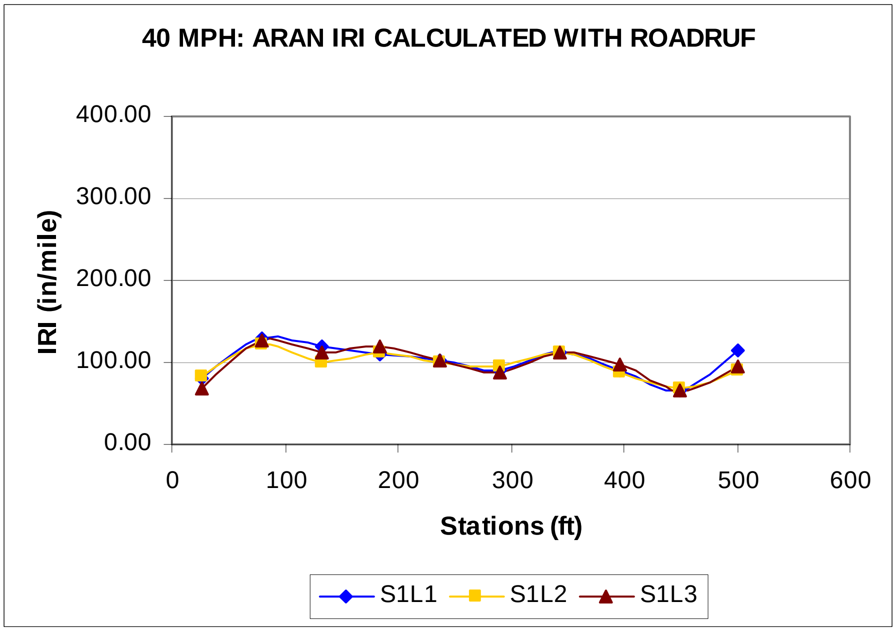


Figure B115: IRI, Route 195, Smooth, Section 1, Left Wheel Path

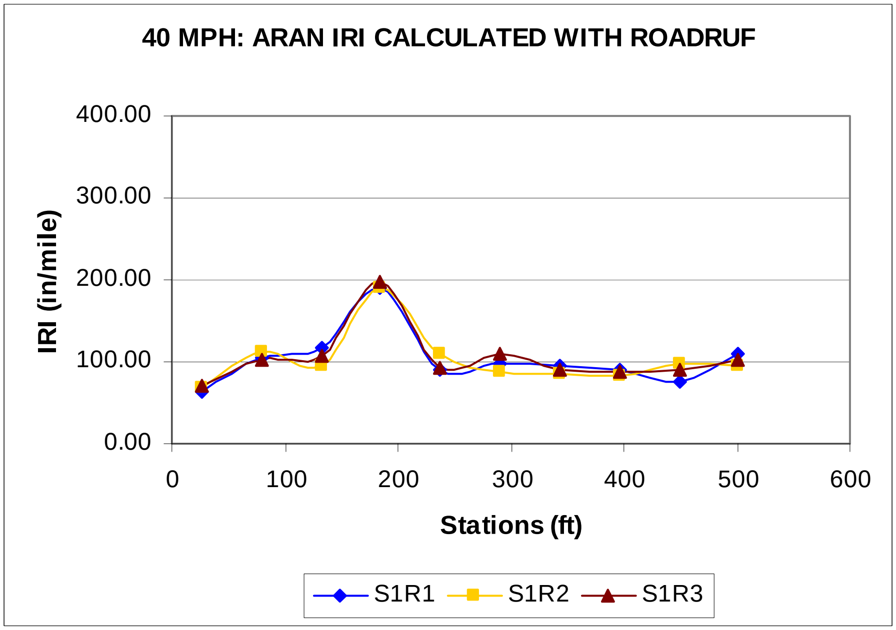


Figure B116: IRI, Route 195, Smooth, Section 1, Right Wheel Path

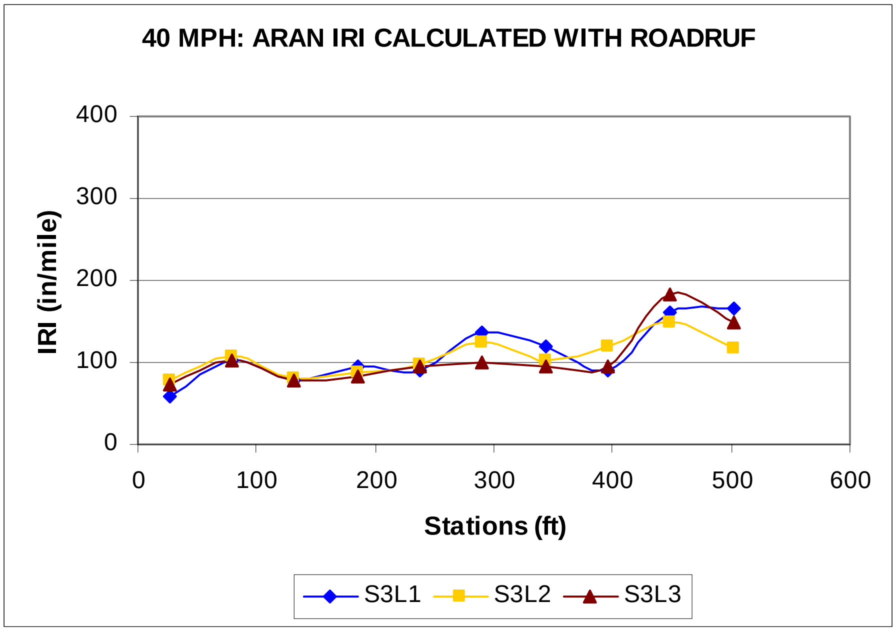


Figure B117: IRI, Route 195, Smooth, Section 3, Left Wheel Path

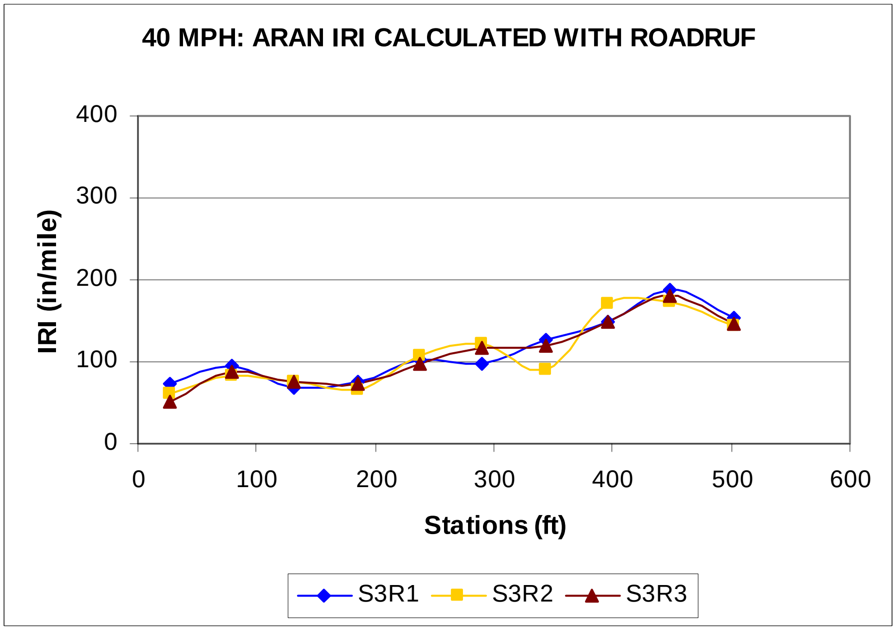


Figure B118: IRI, Route 195, Smooth, Section 3, Right Wheel Path

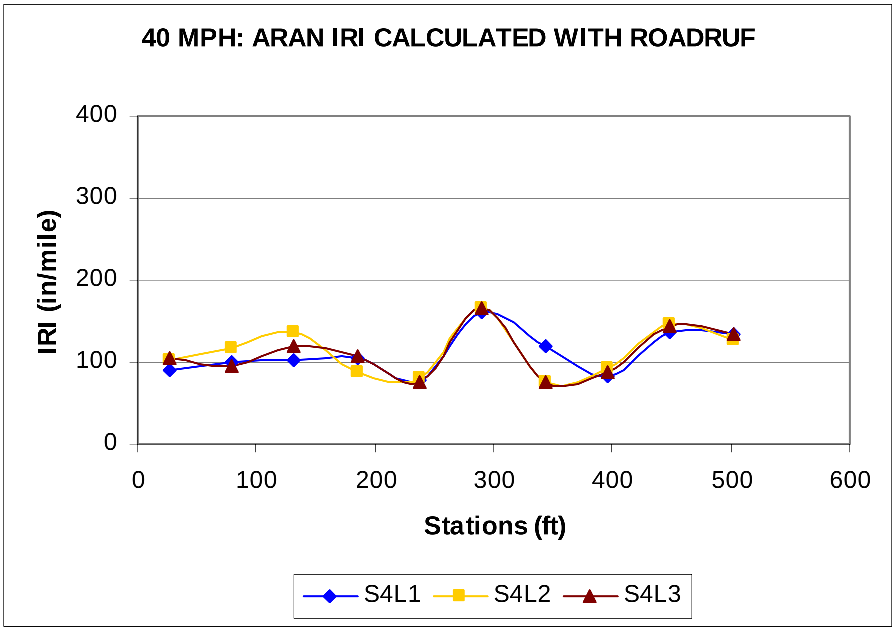


Figure B119: IRI, Route 195, Smooth, Section 4, Left Wheel Path

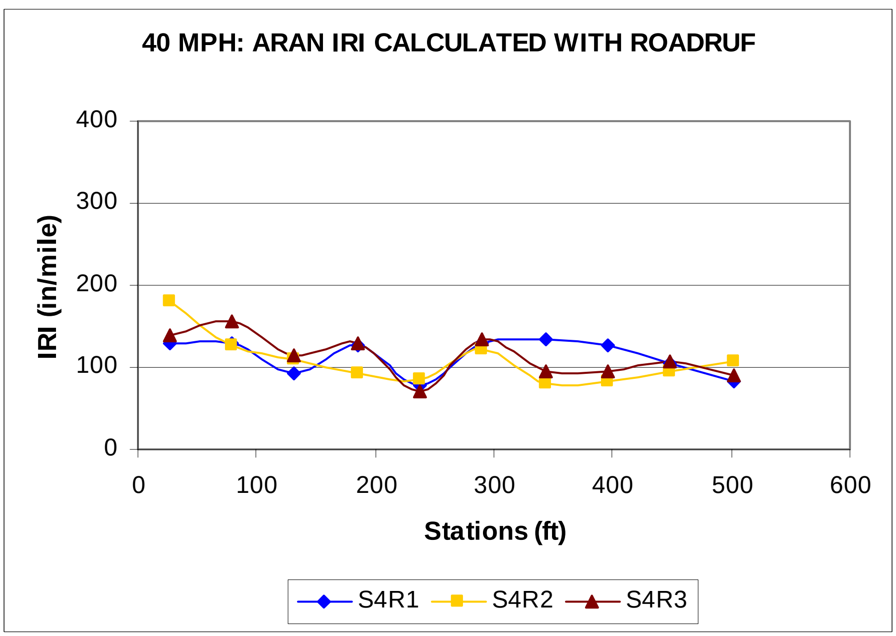


Figure B120: IRI, Route 195, Smooth, Section 4, Right Wheel Path

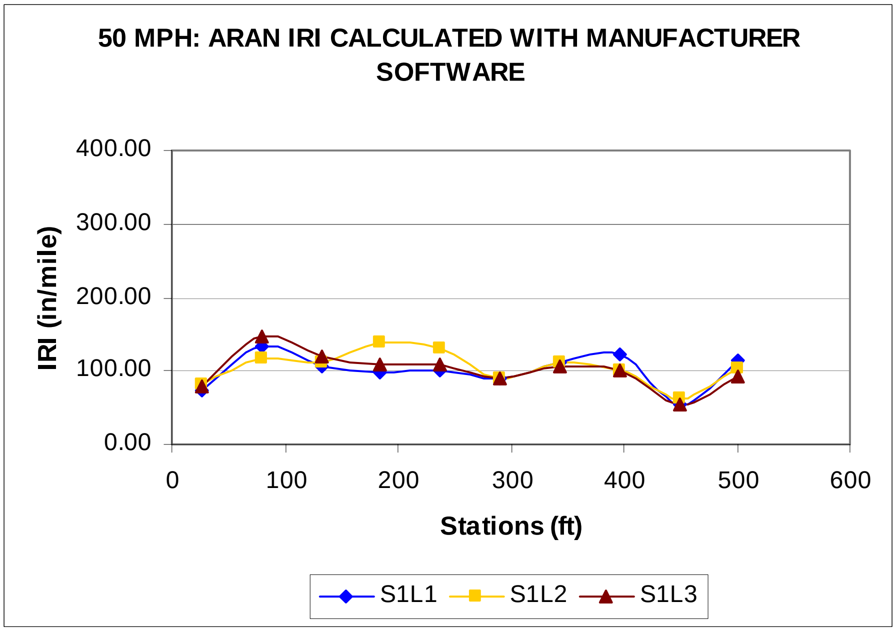


Figure B121: IRI, Route 195, Smooth, Section 1, Left Wheel Path

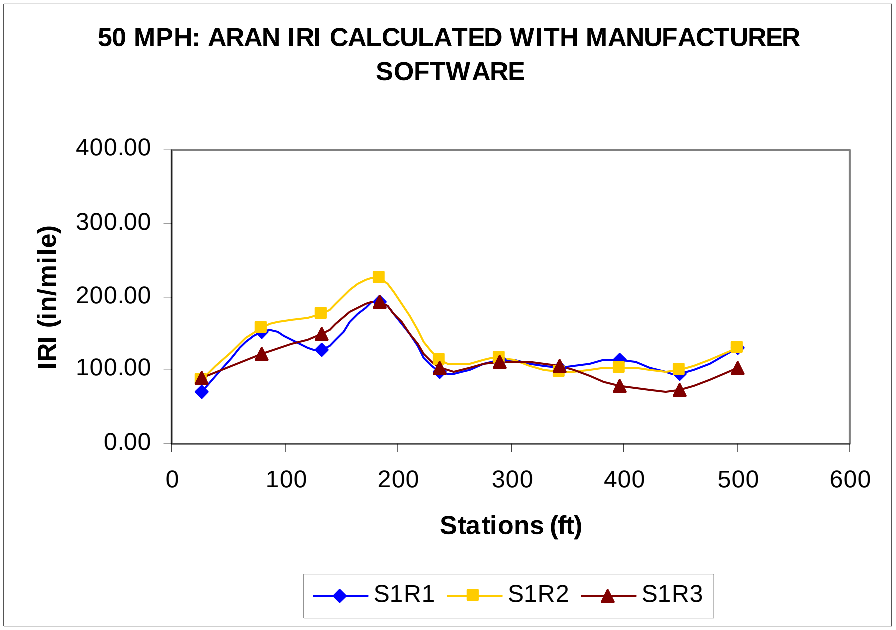


Figure B122: IRI, Route 195, Smooth, Section 1, Right Wheel Path

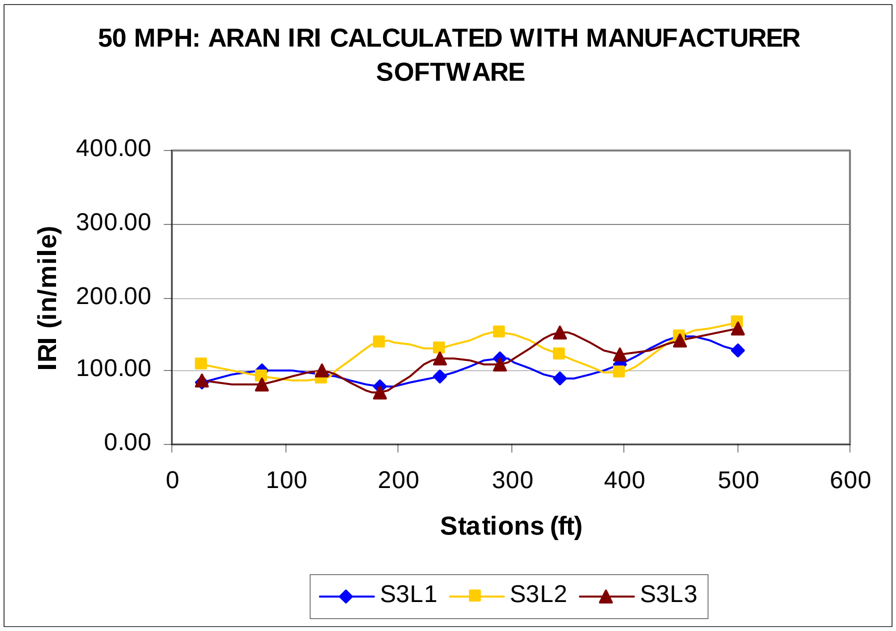


Figure B123: IRI, Route 195, Smooth, Section 3, Left Wheel Path

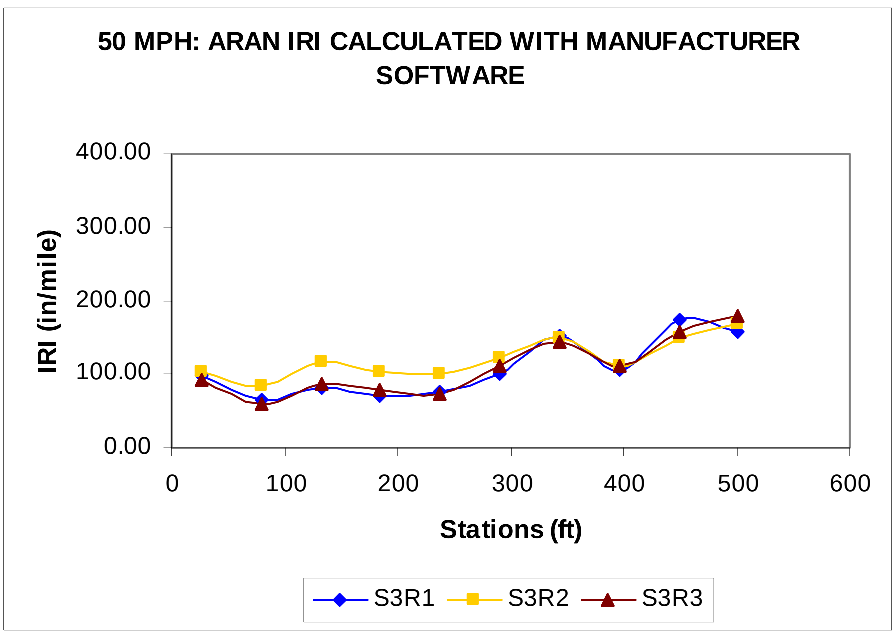


Figure B124: IRI, Route 195, Smooth, Section 3, Right Wheel Path

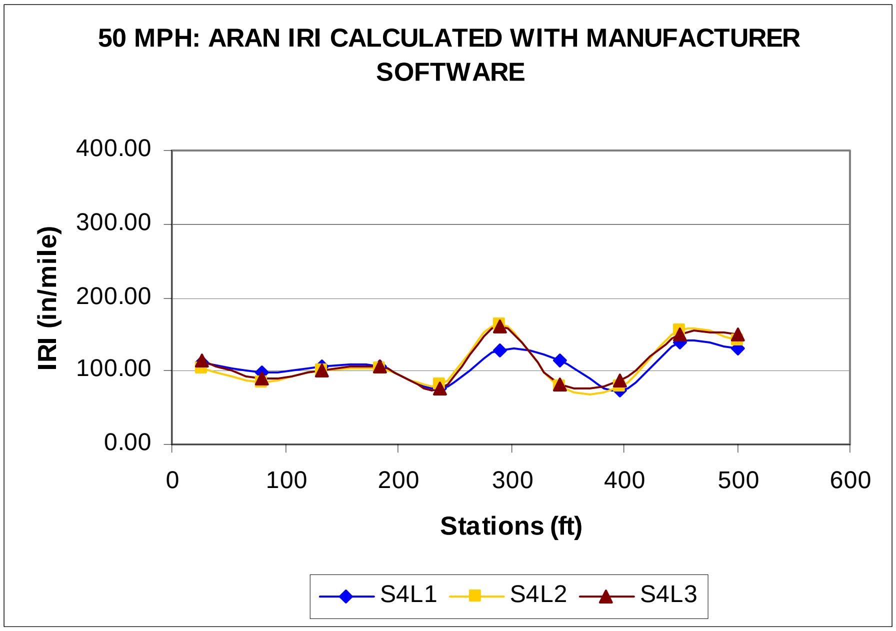


Figure B125: IRI, Route 195, Smooth, Section 4, Left Wheel Path

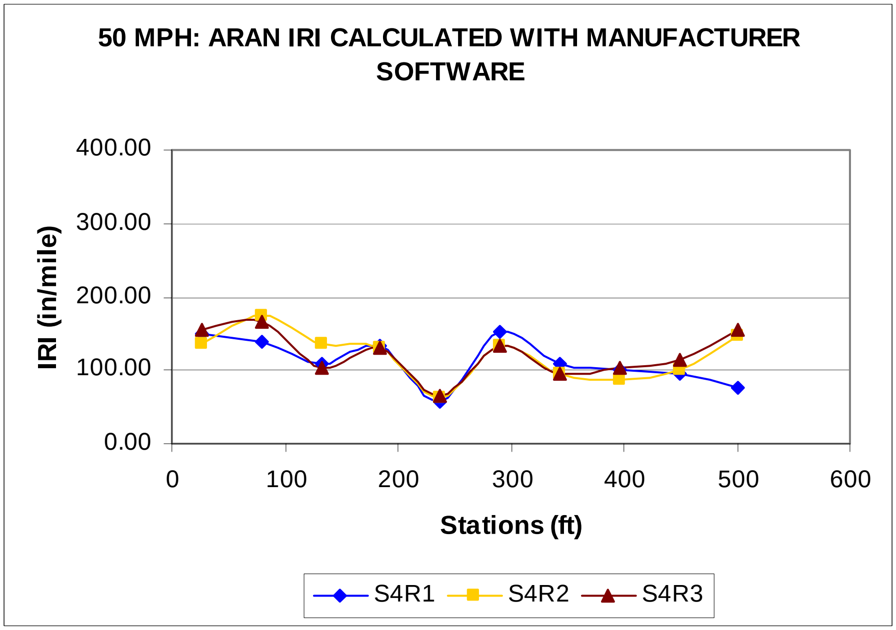


Figure B126: IRI, Route 195, Smooth, Section 4, Right Wheel Path

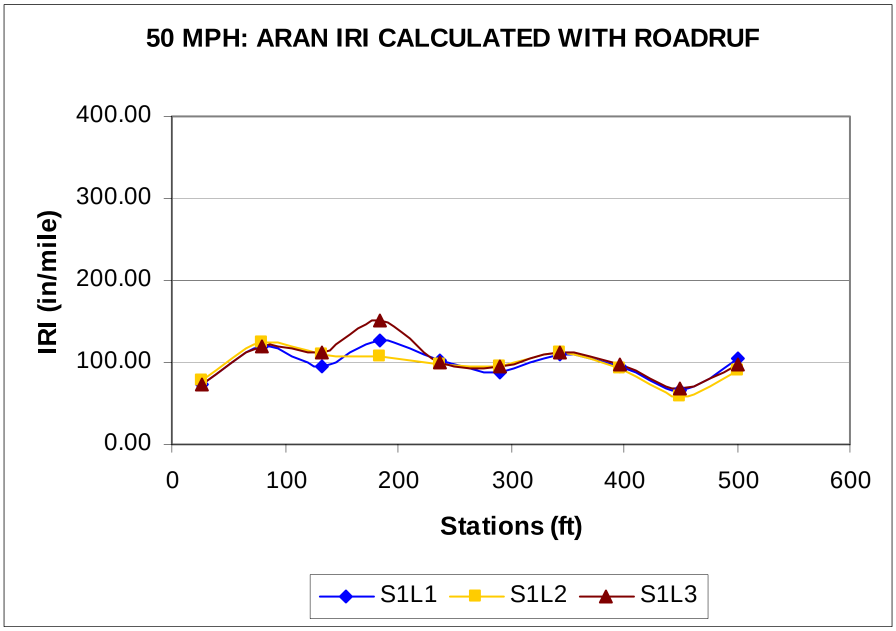


Figure B127: IRI, Route 195, Smooth, Section 1, Left Wheel Path

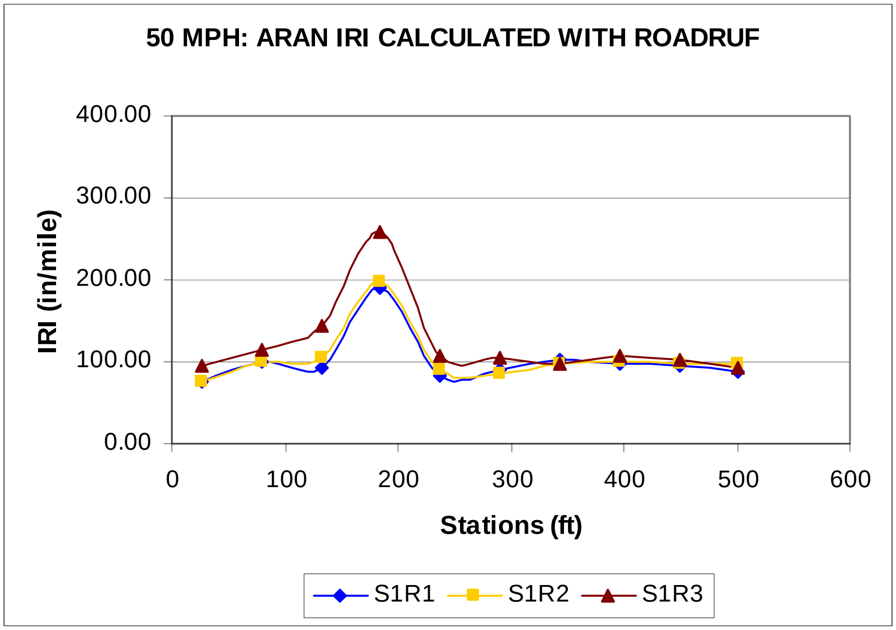


Figure B128: IRI, Route 195, Smooth, Section 1, Right Wheel Path

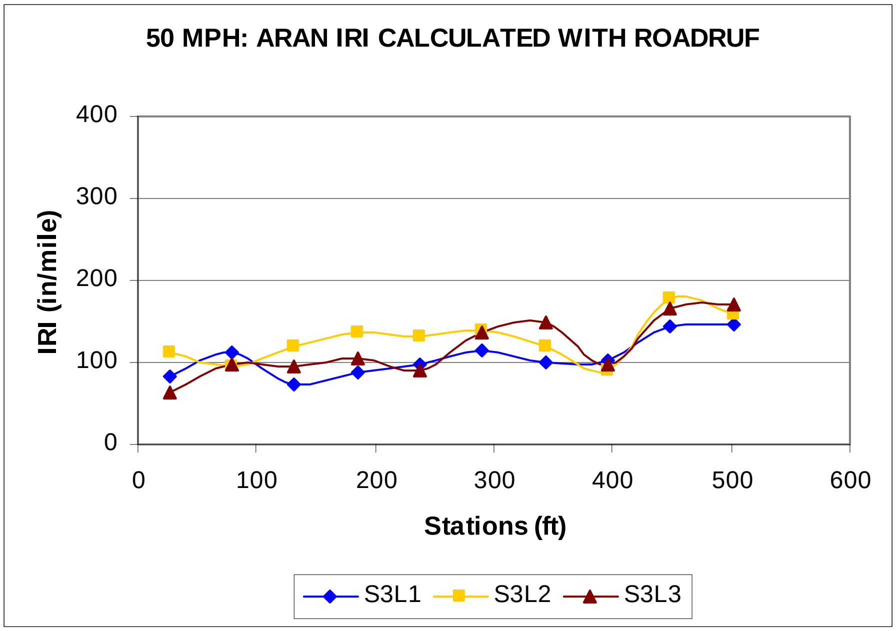


Figure B129: IRI, Route 195, Smooth, Section 3, Left Wheel Path

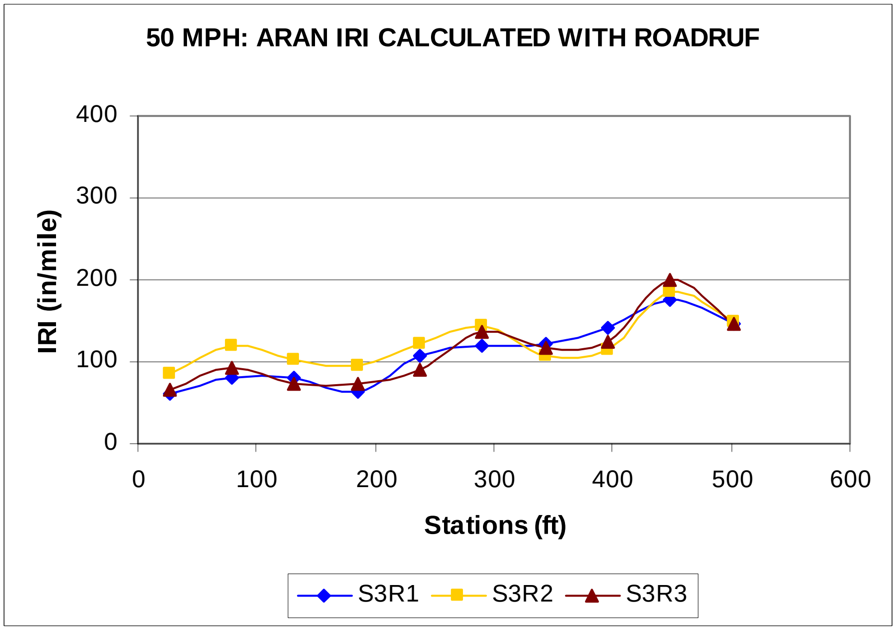


Figure B130: IRI, Route 195, Smooth, Section 3, Right Wheel Path

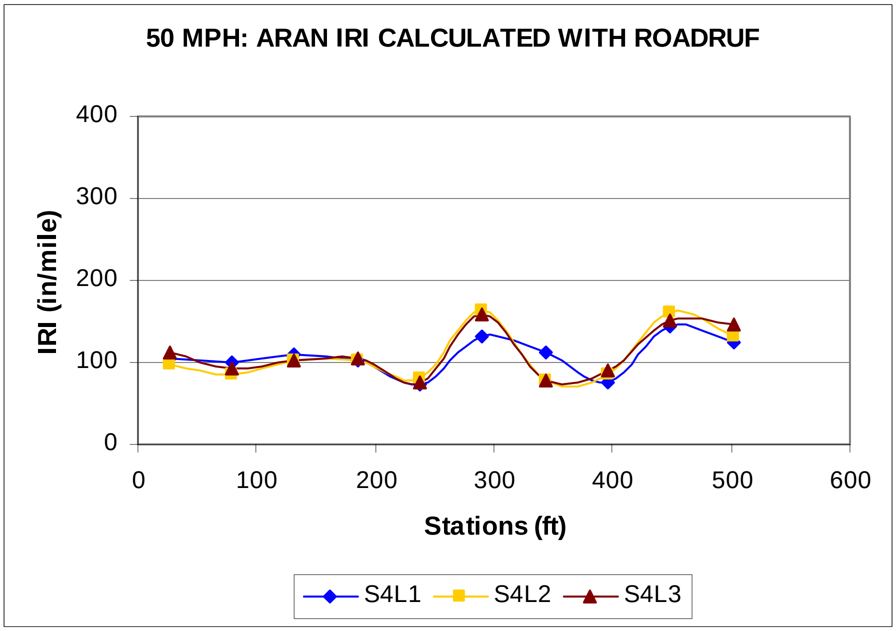


Figure B131: IRI, Route 195, Smooth, Section 4, Left Wheel Path

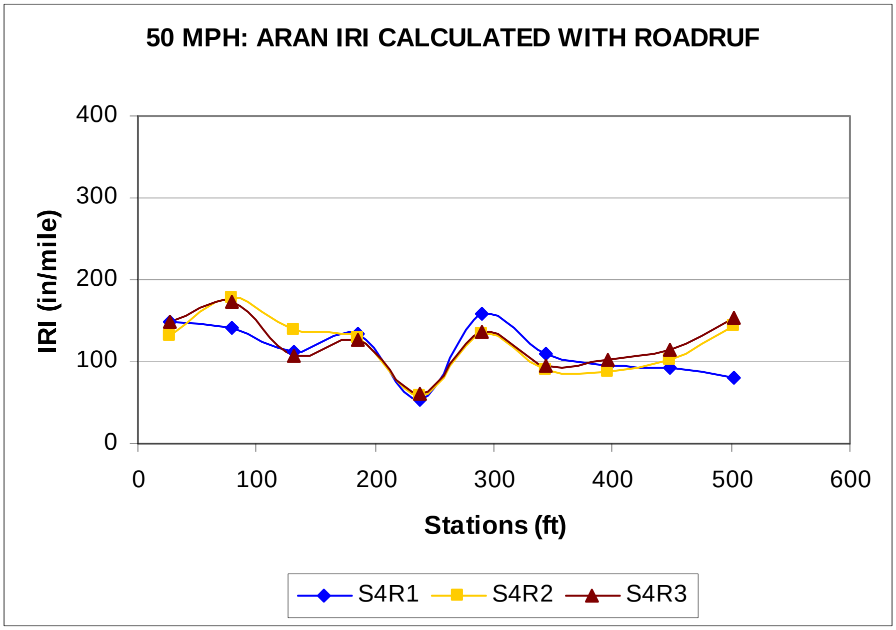


Figure B132: IRI, Route 195, Smooth, Section 4, Right Wheel Path

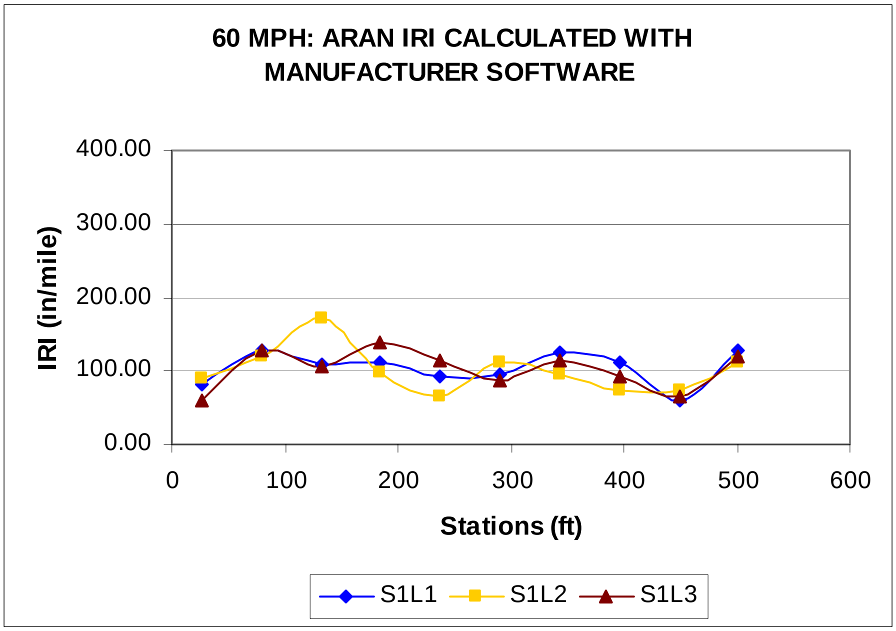


Figure B133: IRI, Route 195, Smooth, Section 1, Left Wheel Path

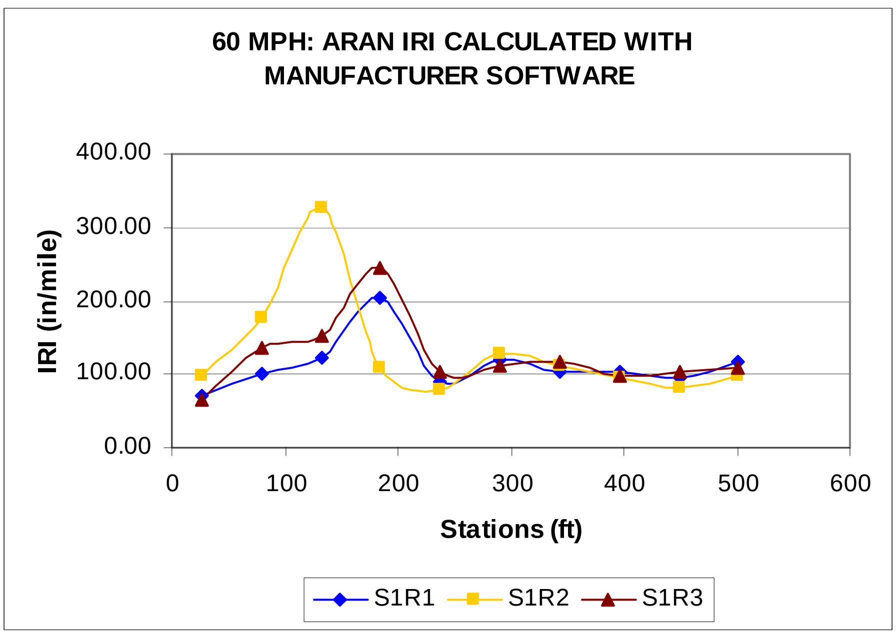


Figure B134: IRI, Route 195, Smooth, Section 1, Right Wheel Path

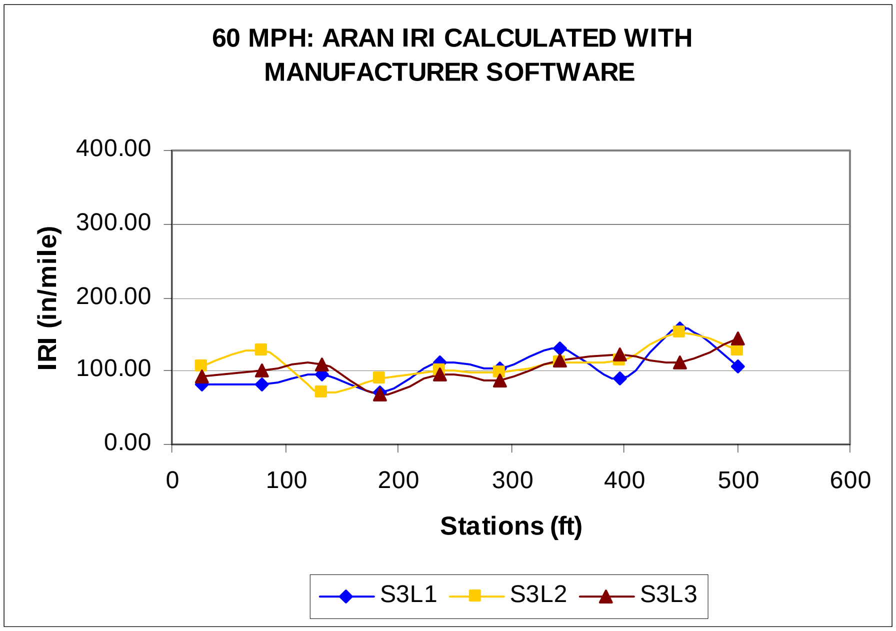


Figure B135: IRI, Route 195, Smooth, Section 3, Left Wheel Path

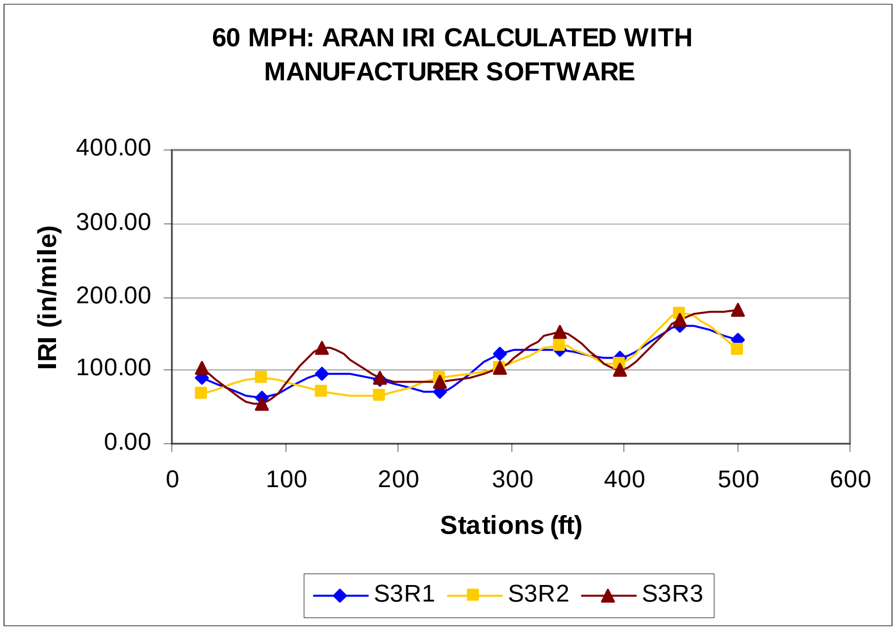


Figure B136: IRI, Route 195, Smooth, Section 3, Right Wheel Path

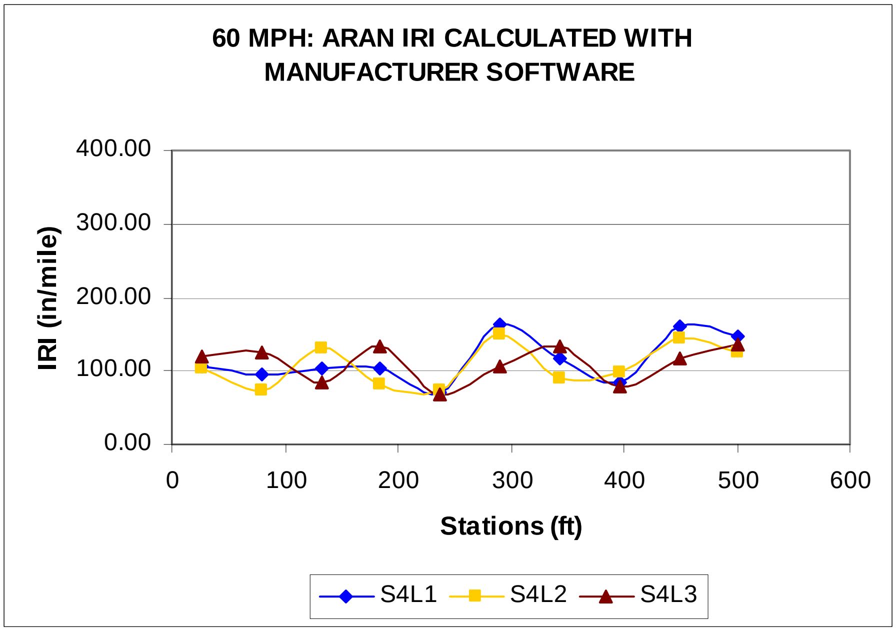


Figure B137: IRI, Route 195, Smooth, Section 4, Left Wheel Path

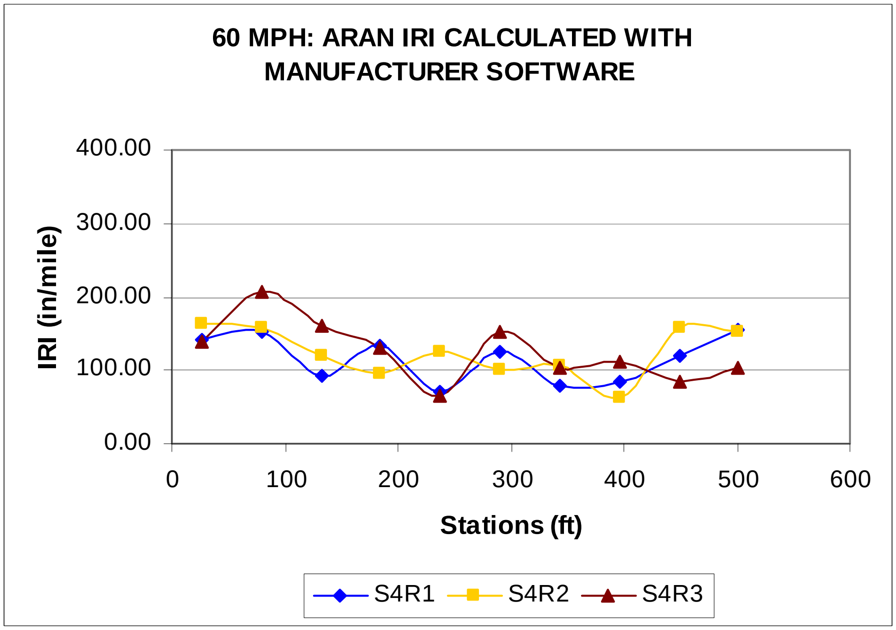


Figure B138: IRI, Route 195, Smooth, Section 4, Right Wheel Path

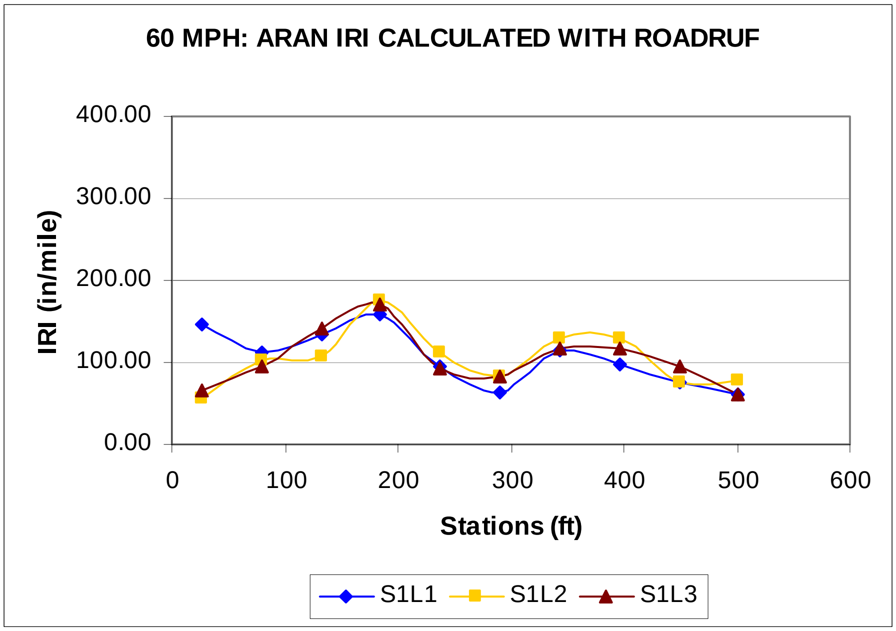


Figure B139: IRI, Route 195, Smooth, Section 1, Left Wheel Path

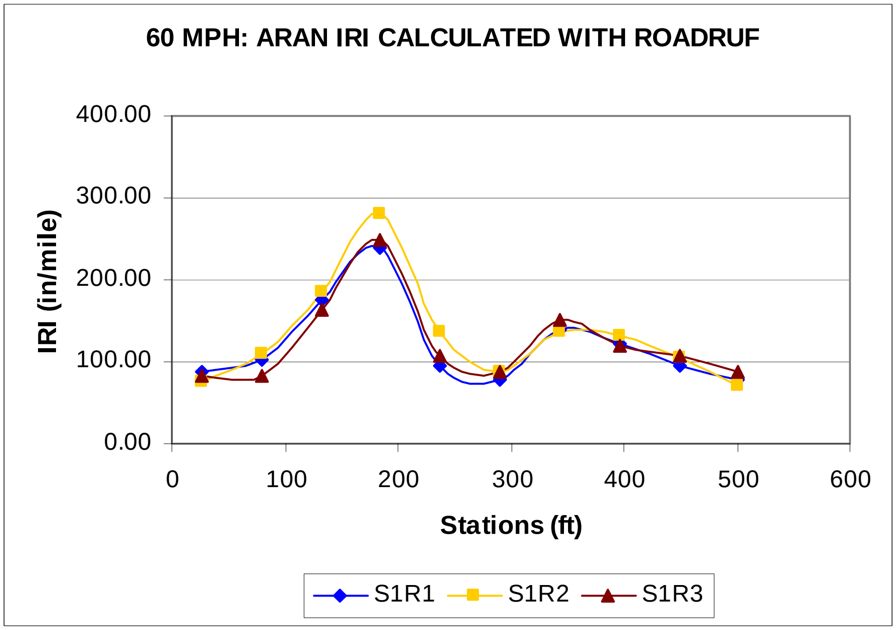


Figure B140: IRI, Route 195, Smooth, Section 1, Right Wheel Path

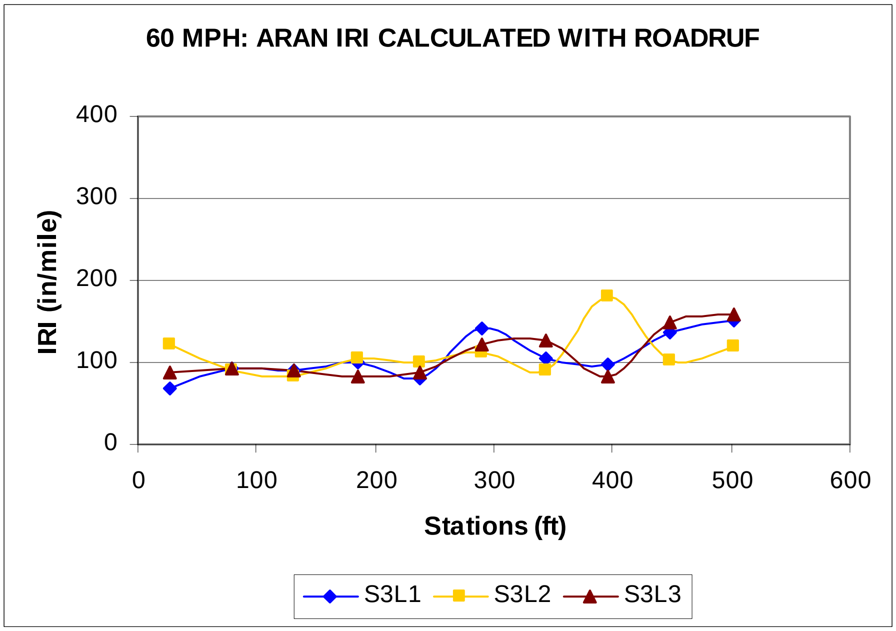


Figure B141: IRI, Route 195, Smooth, Section 3, Left Wheel Path

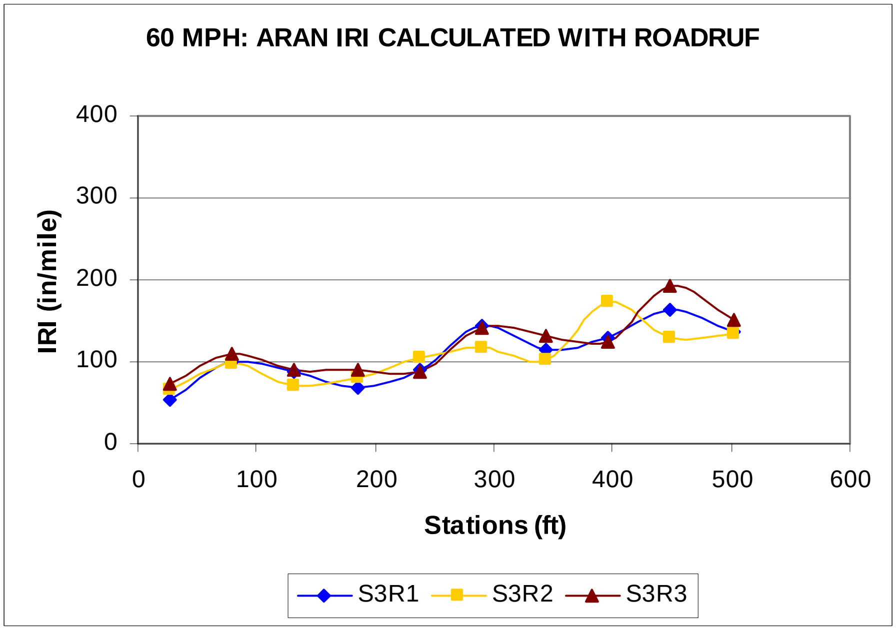


Figure B142: IRI, Route 195, Smooth, Section 3, Right Wheel Path

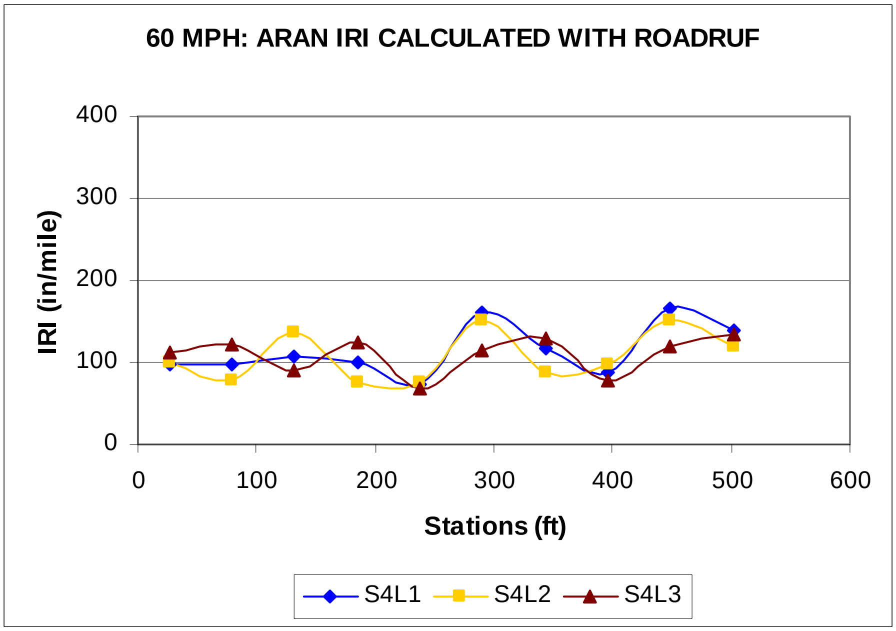


Figure B143: IRI, Route 195, Smooth, Section 4, Left Wheel Path

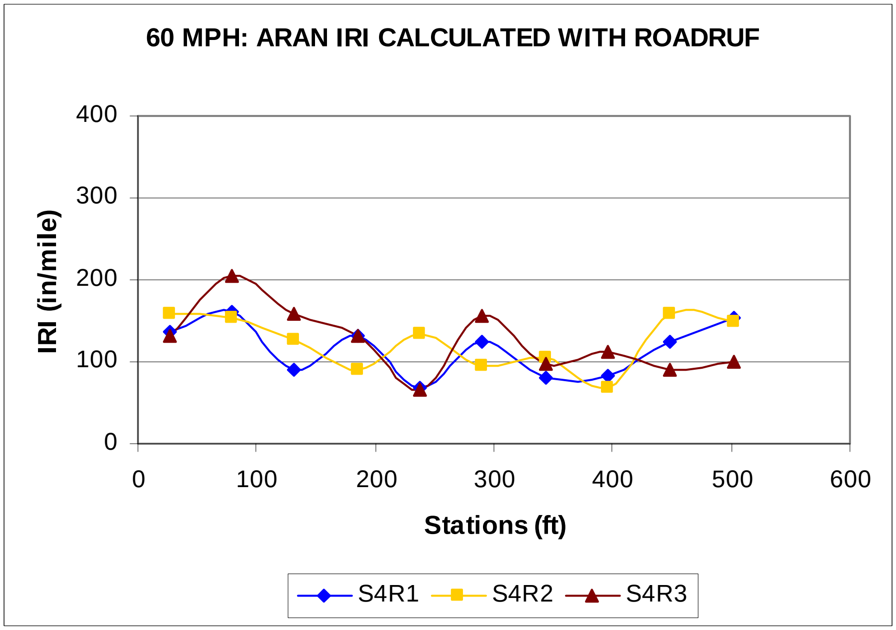


Figure B144: IRI, Route 195, Smooth, Section 4, Right Wheel Path

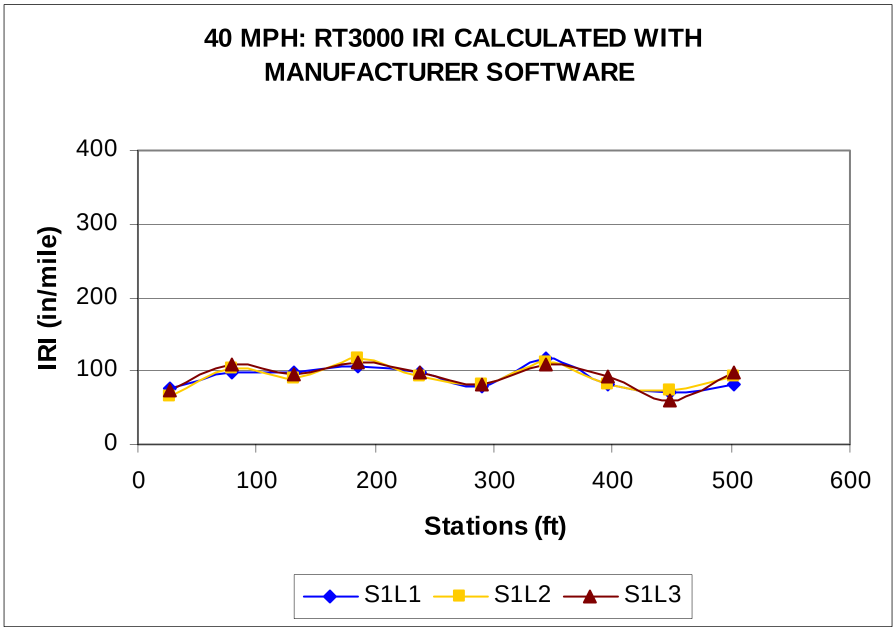


Figure B145: IRI, Route 195, Smooth, Section 1, Left Wheel Path

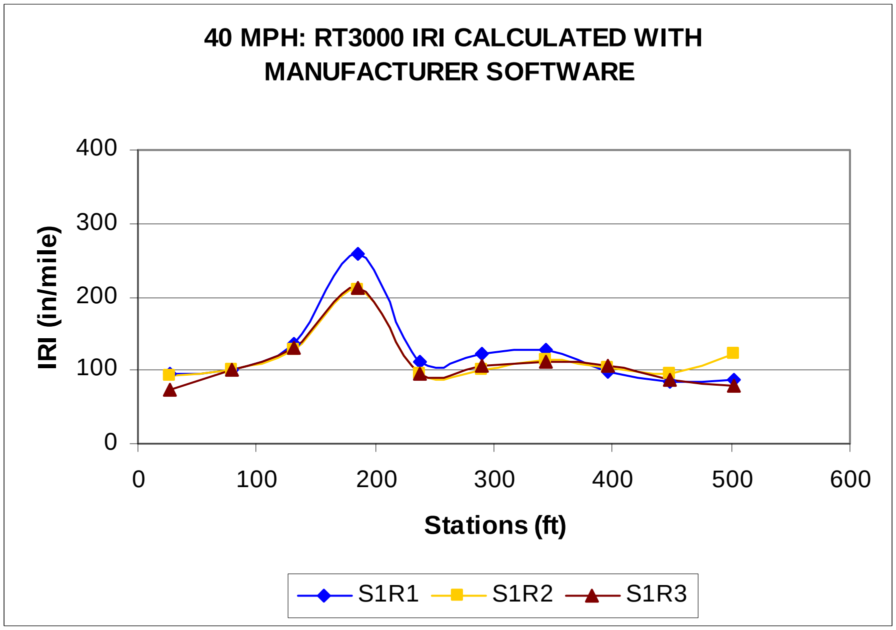


Figure B146: IRI, Route 195, Smooth, Section 1, Right Wheel Path

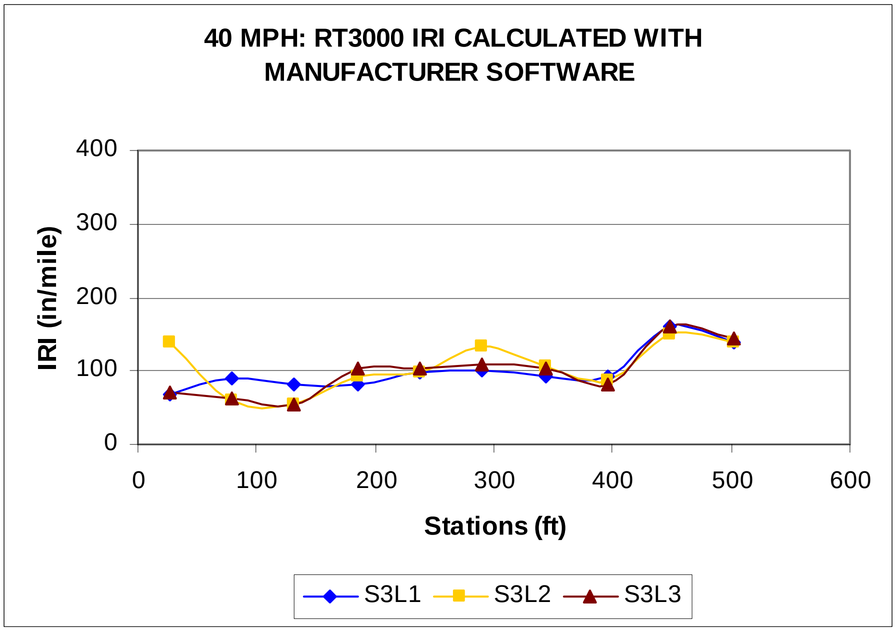


Figure B147: IRI, Route 195, Smooth, Section 3, Left Wheel Path

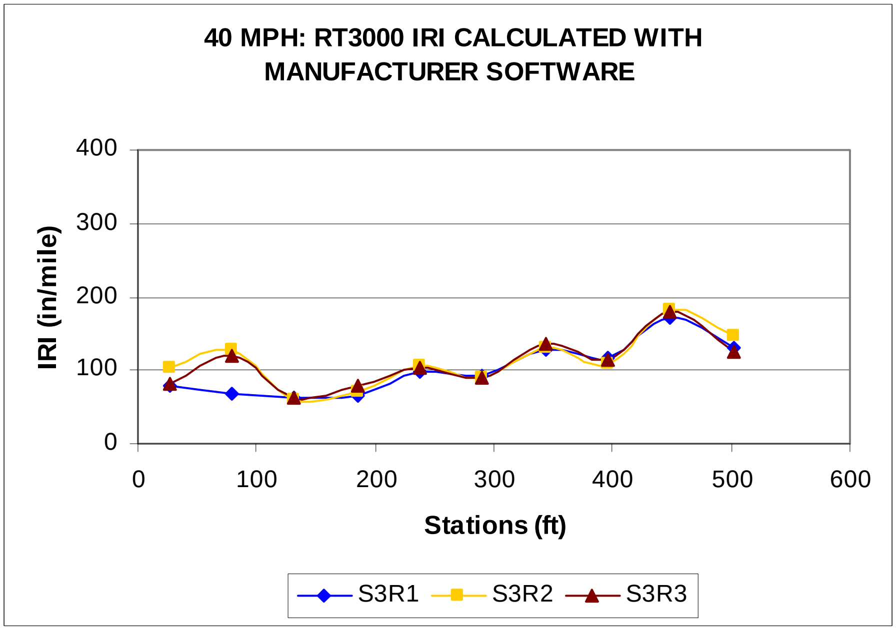


Figure B148: IRI, Route 195, Smooth, Section 3, Right Wheel Path

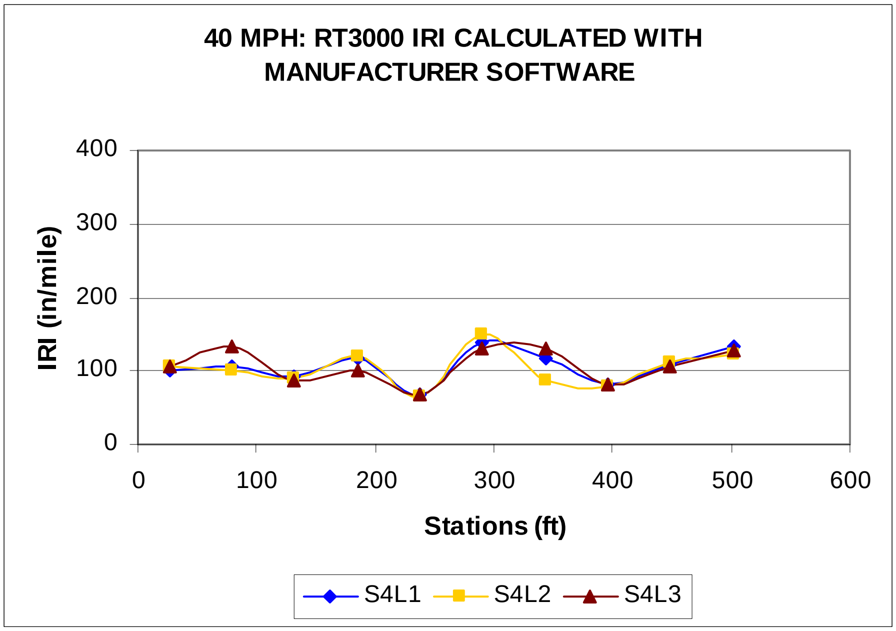


Figure B149: IRI, Route 195, Smooth, Section 4, Left Wheel Path

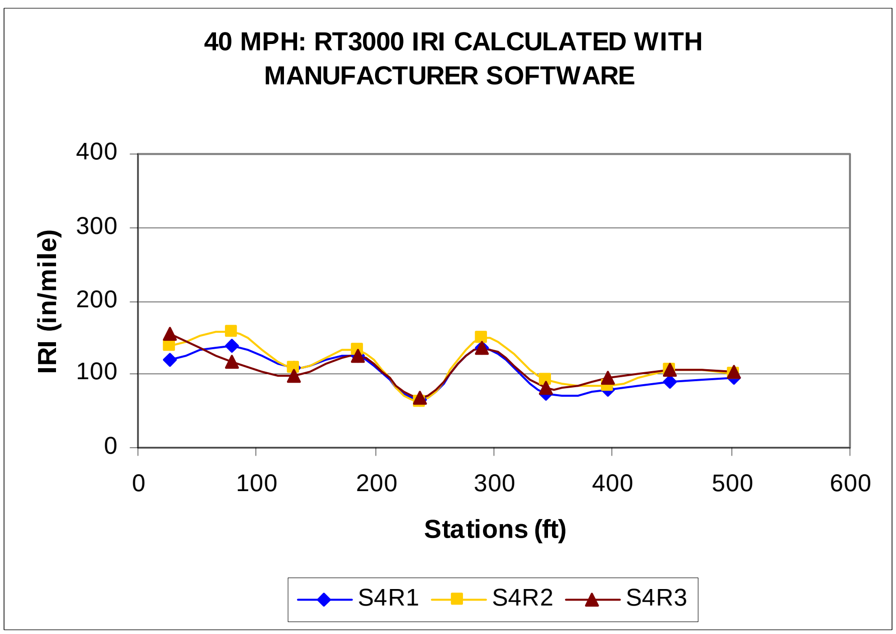


Figure B150: IRI, Route 195, Smooth, Section 4, Right Wheel Path

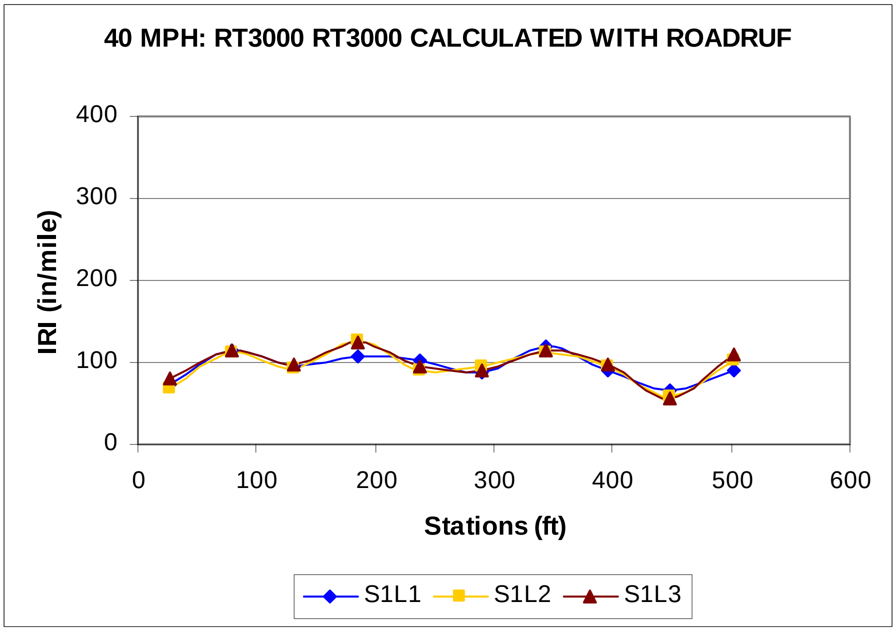


Figure B151: IRI, Route 195, Smooth, Section 1, Left Wheel Path

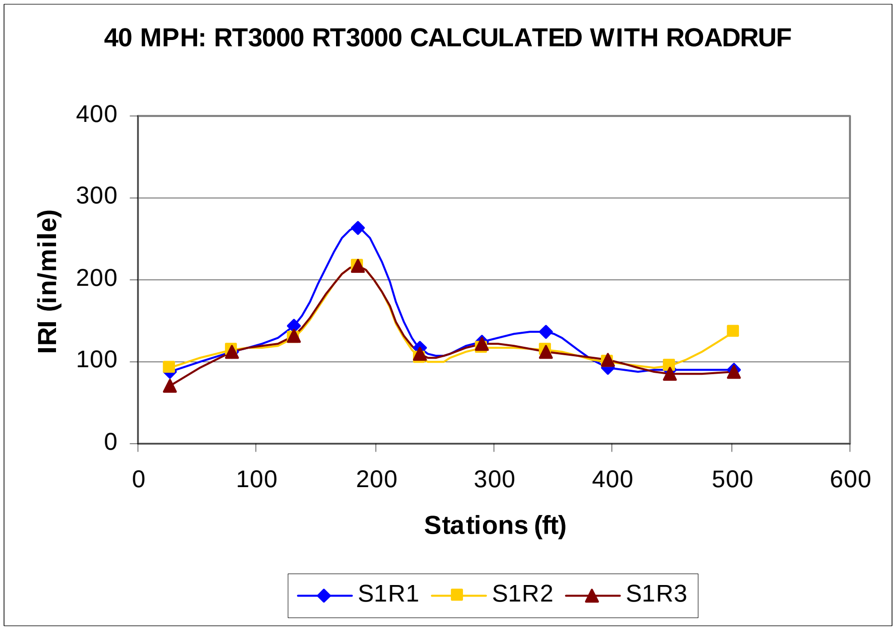


Figure B152: IRI, Route 195, Smooth, Section 1, Right Wheel Path

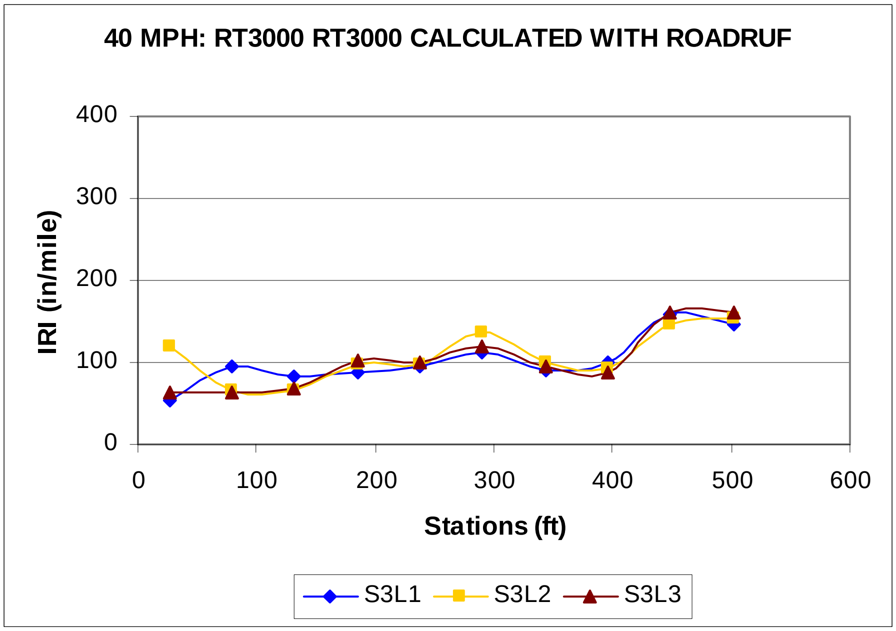


Figure B153: IRI, Route 195, Smooth, Section 3, Left Wheel Path

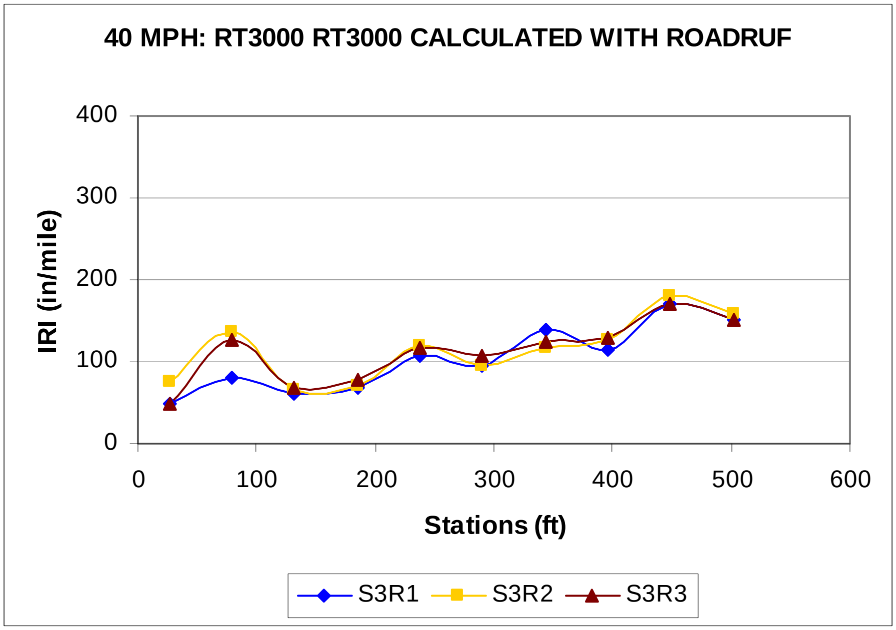


Figure B154: IRI, Route 195, Smooth, Section 3, Right Wheel Path

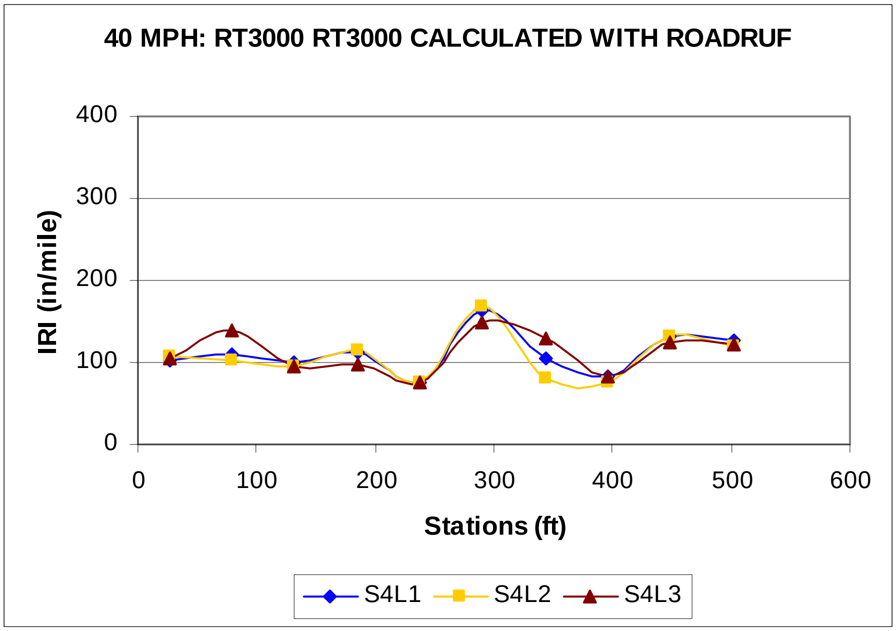


Figure B155: IRI, Route 195, Smooth, Section 4, Left Wheel Path

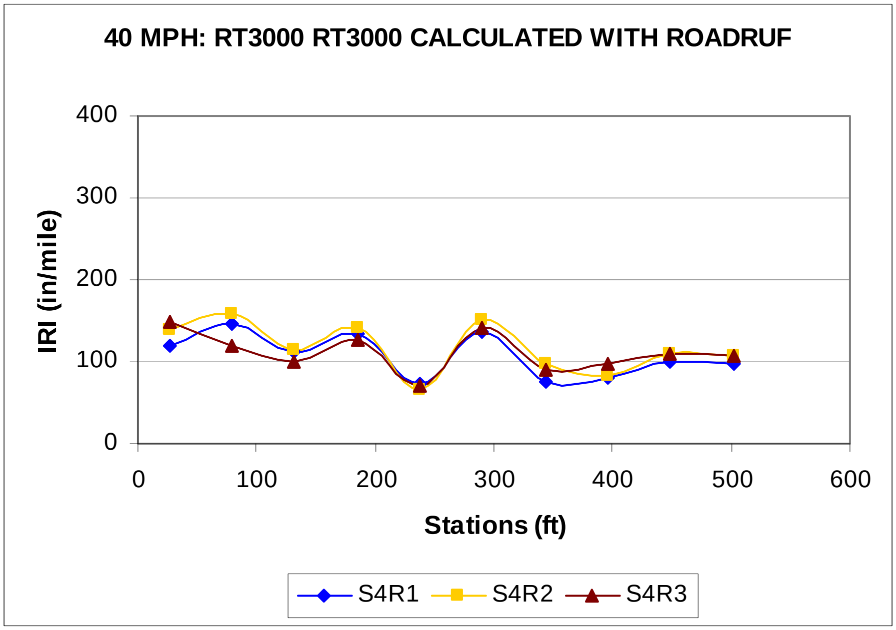


Figure B156: IRI, Route 195, Smooth, Section 4, Right Wheel Path

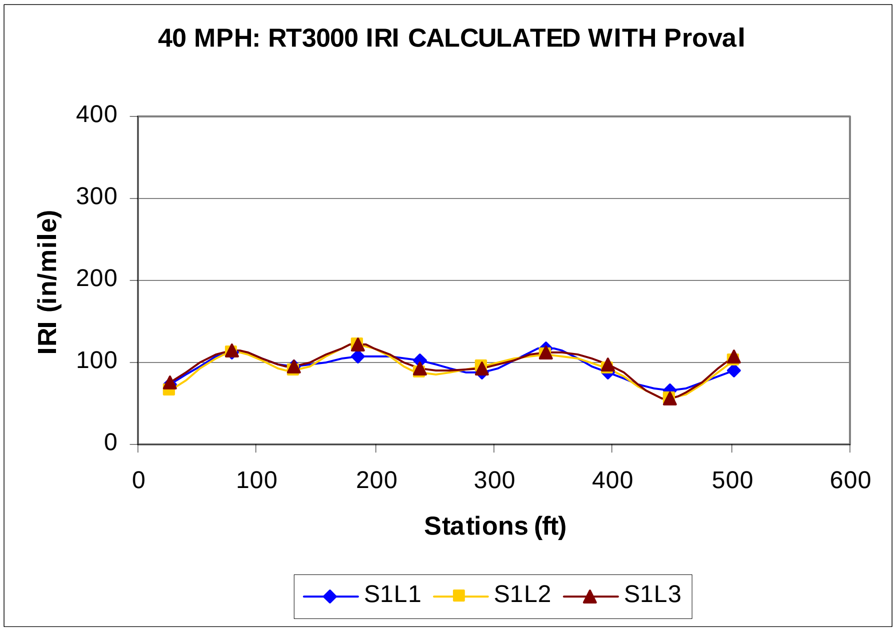


Figure B157: IRI, Route 195, Smooth, Section 1, Left Wheel Path

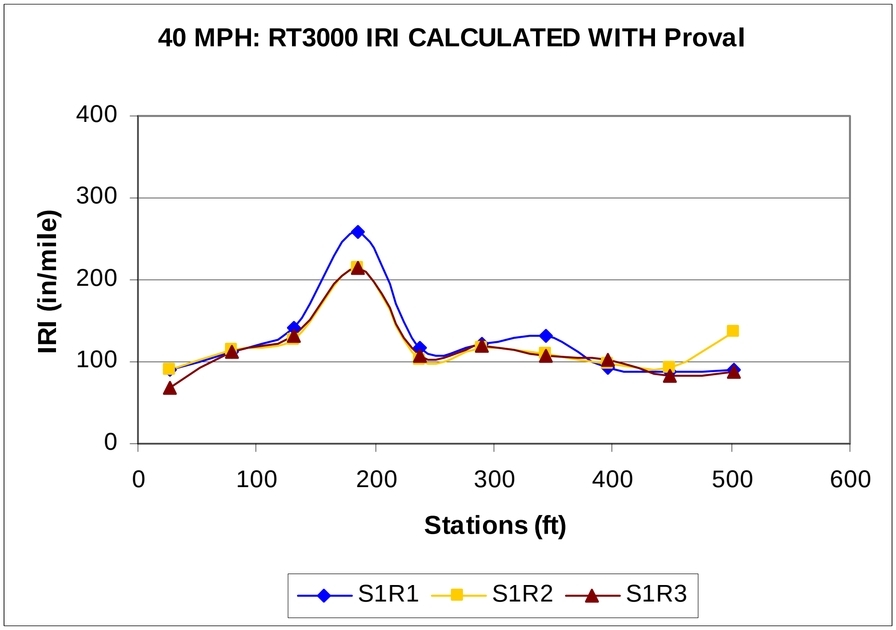


Figure B158: IRI, Route 195, Smooth, Section 1, Right Wheel Path

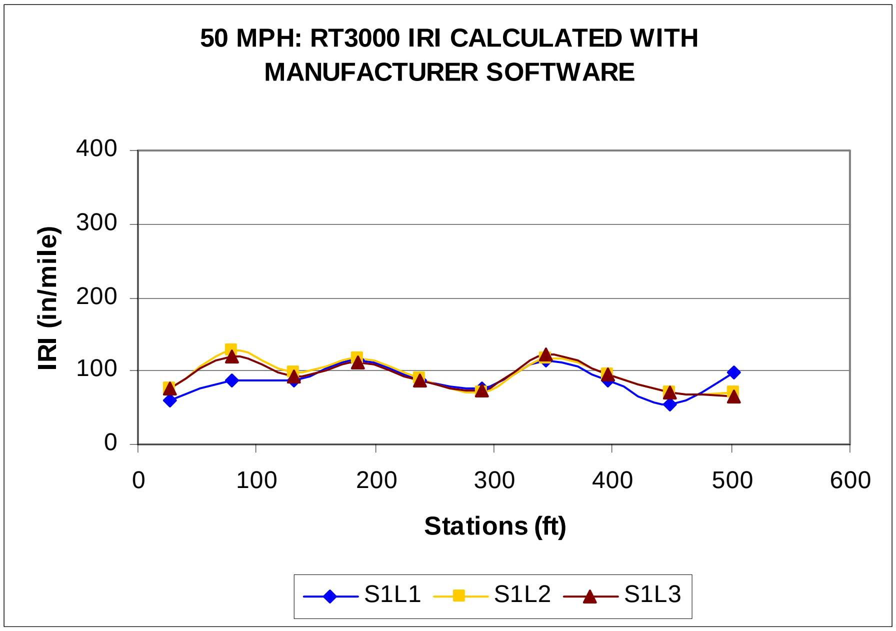


Figure B159: IRI, Route 195, Smooth, Section 1, Left Wheel Path

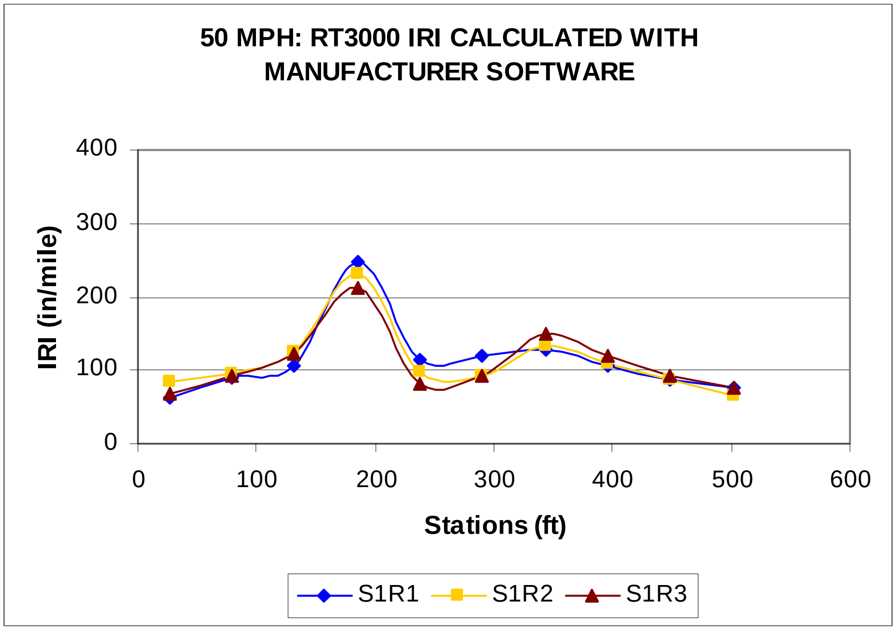


Figure B160: IRI, Route 195, Smooth, Section 1, Right Wheel Path

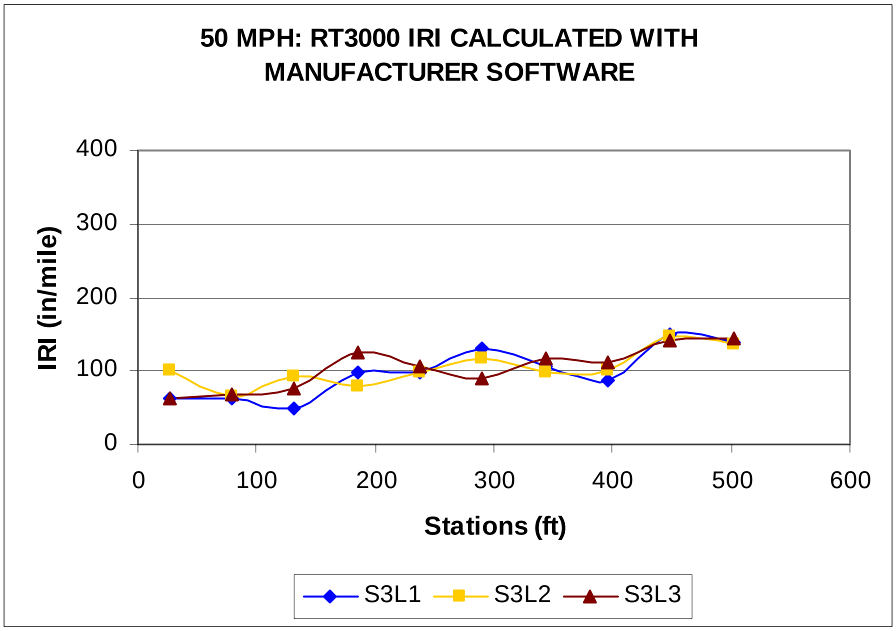


Figure B161: IRI, Route 195, Smooth, Section 3, Left Wheel Path

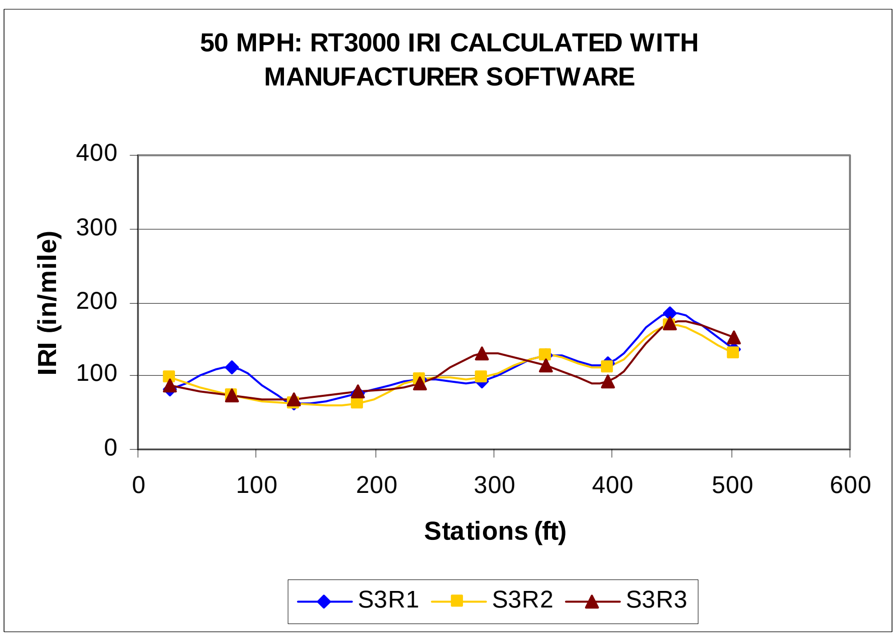


Figure B162: IRI, Route 195, Smooth, Section 3, Right Wheel Path

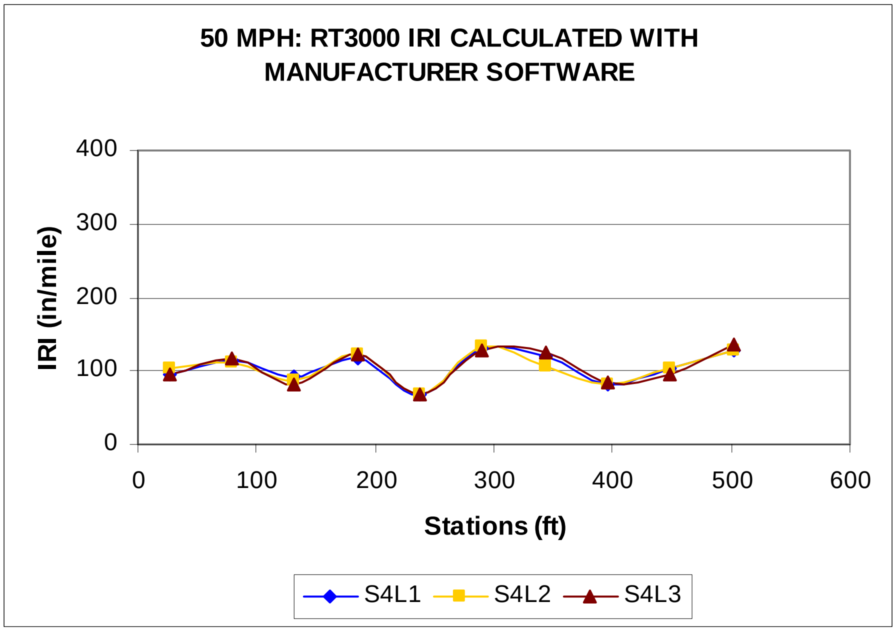


Figure B163: IRI, Route 195, Smooth, Section 4, Left Wheel Path

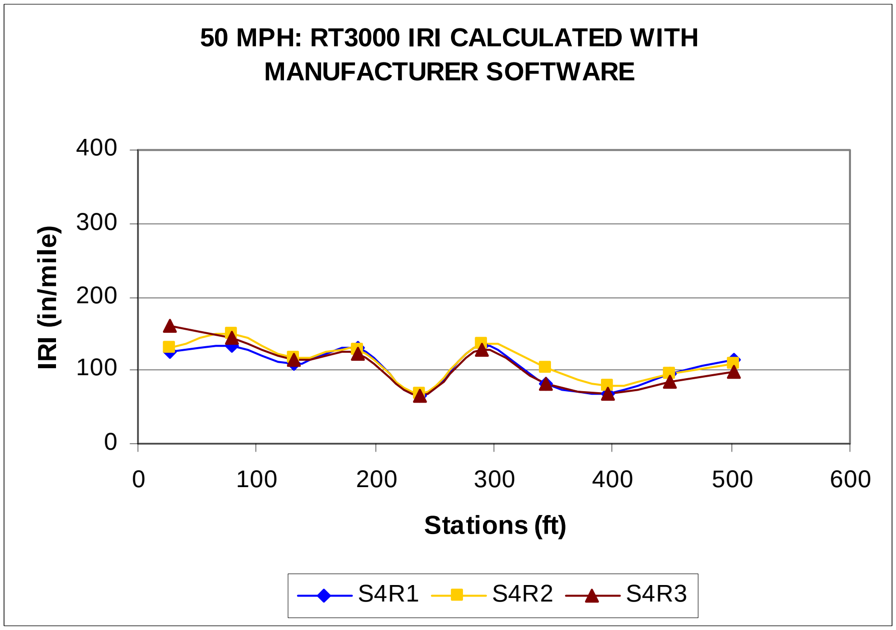


Figure B164: IRI, Route 195, Smooth, Section 4, Right Wheel Path

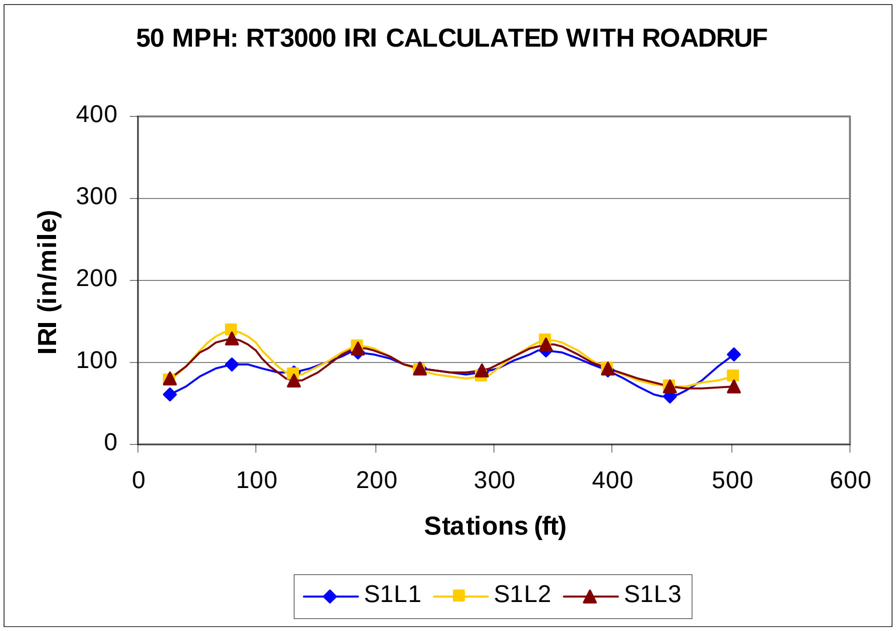


Figure B165: IRI, Route 195, Smooth, Section 1, Left Wheel Path

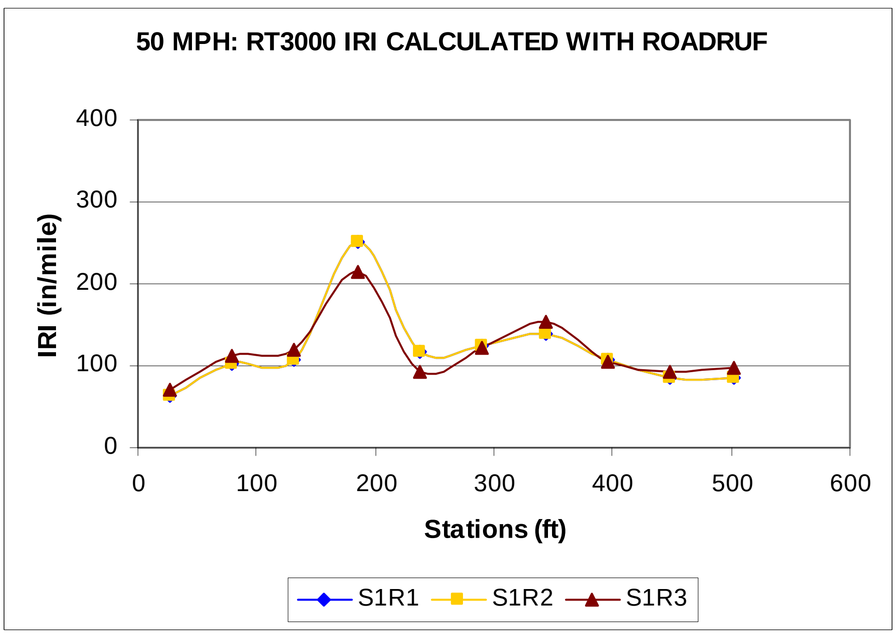


Figure B166: IRI, Route 195, Smooth, Section 1, Right Wheel Path

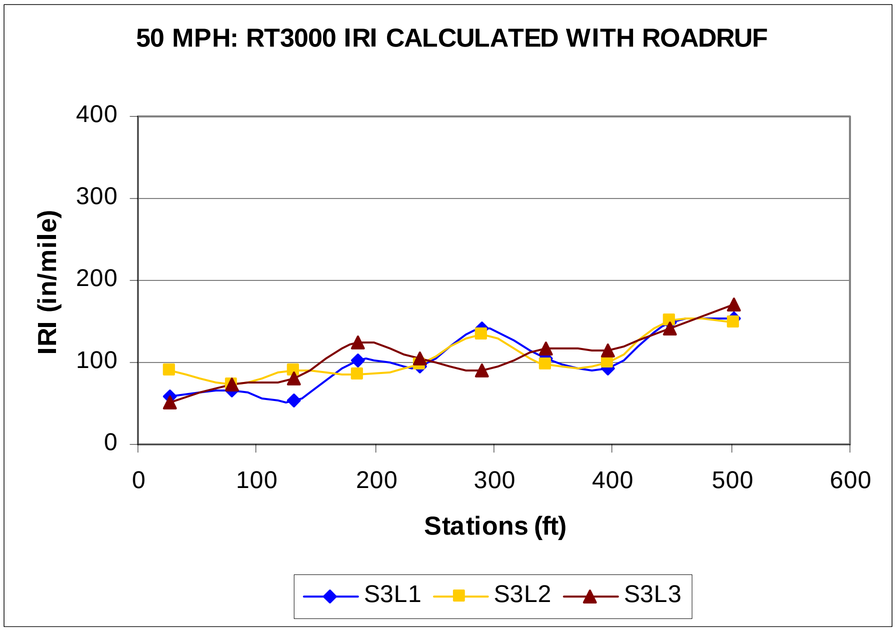


Figure B167: IRI, Route 195, Smooth, Section 3, Left Wheel Path

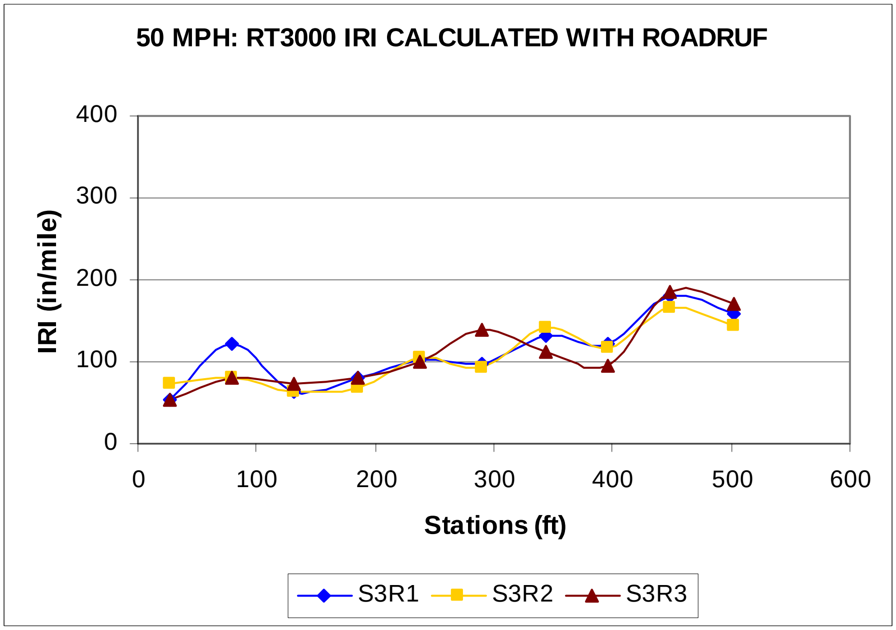


Figure B168: IRI, Route 195, Smooth, Section 3, Right Wheel Path

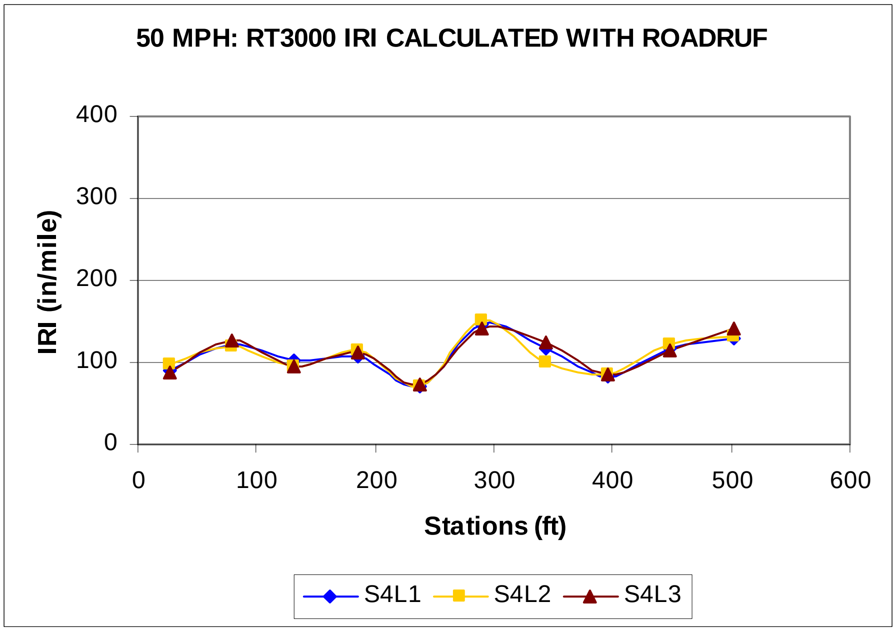


Figure B169: IRI, Route 195, Smooth, Section 4, Left Wheel Path

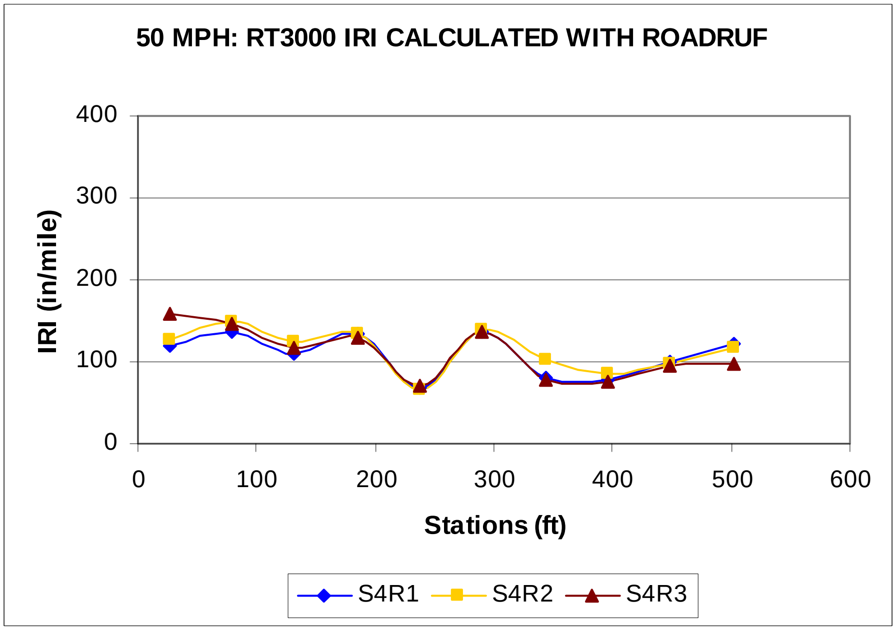


Figure B170: IRI, Route 195, Smooth, Section 4, Right Wheel Path

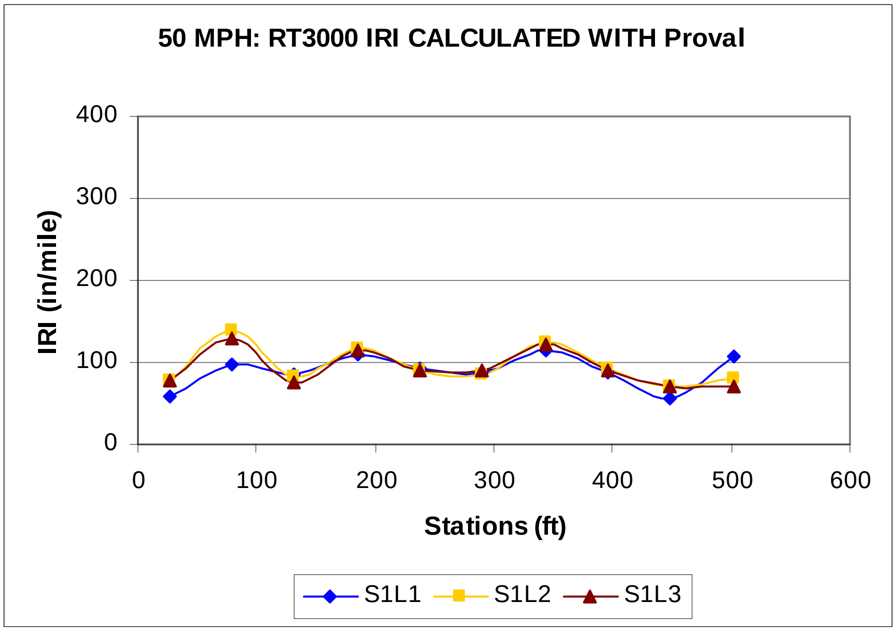


Figure B171: IRI, Route 195, Smooth, Section 1, Left Wheel Path

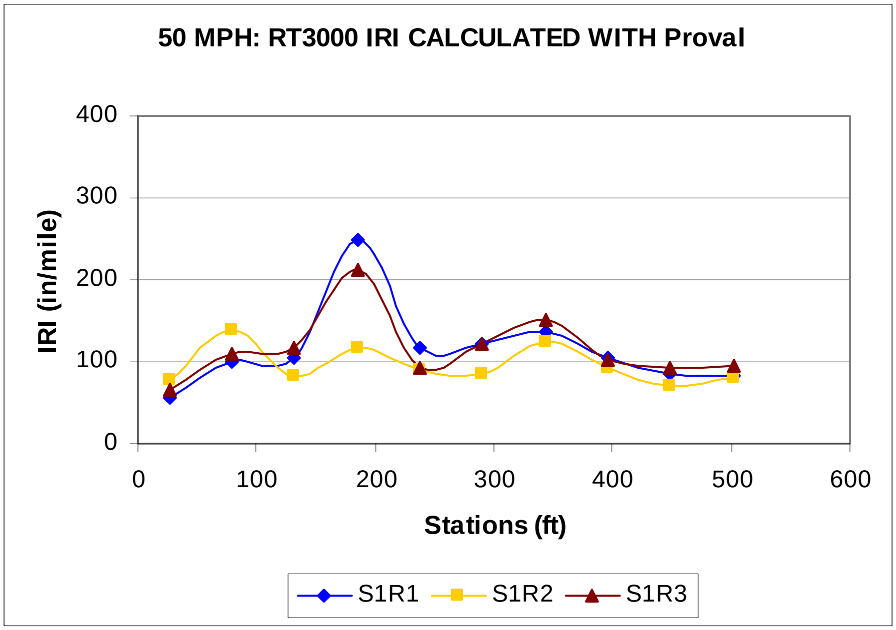


Figure B172: IRI, Route 195, Smooth, Section 1, Right Wheel Path

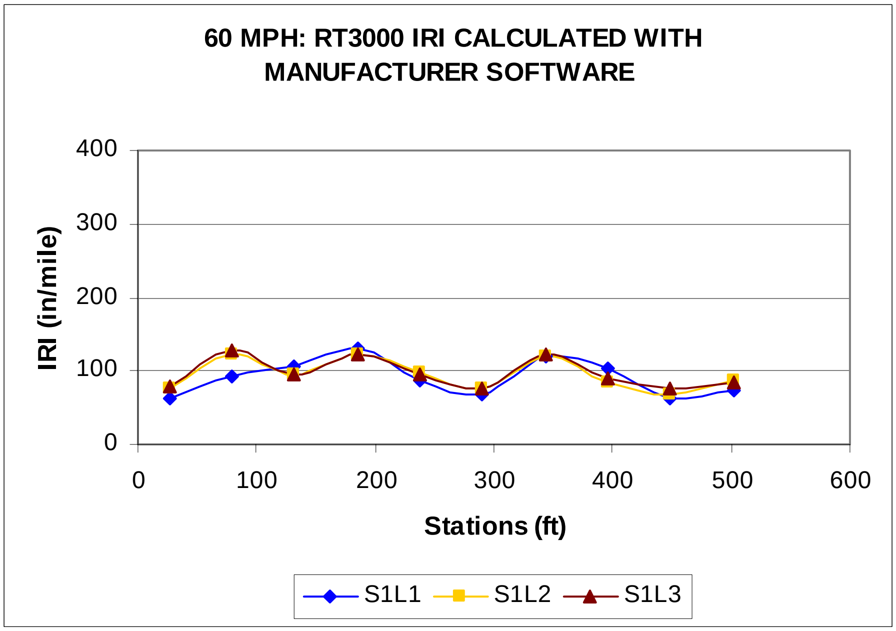


Figure B173: IRI, Route 195, Smooth, Section 1, Left Wheel Path

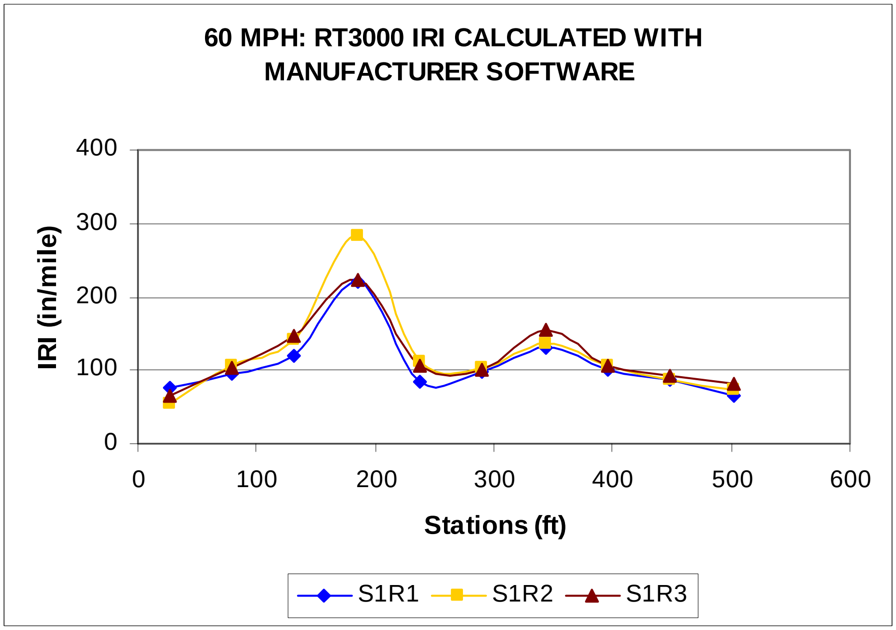


Figure B174: IRI, Route 195, Smooth, Section 1, Right Wheel Path

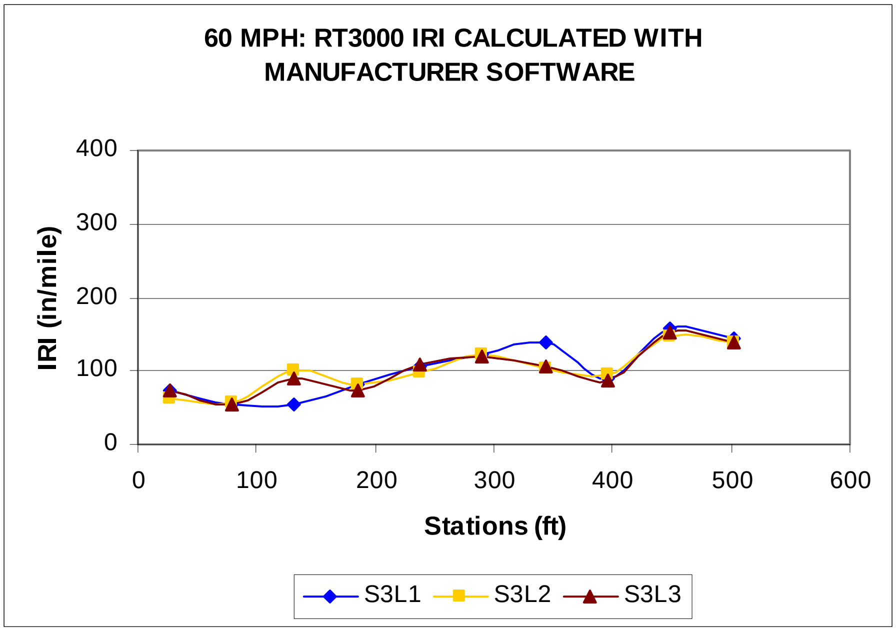


Figure B175: IRI, Route 195, Smooth, Section 3, Left Wheel Path

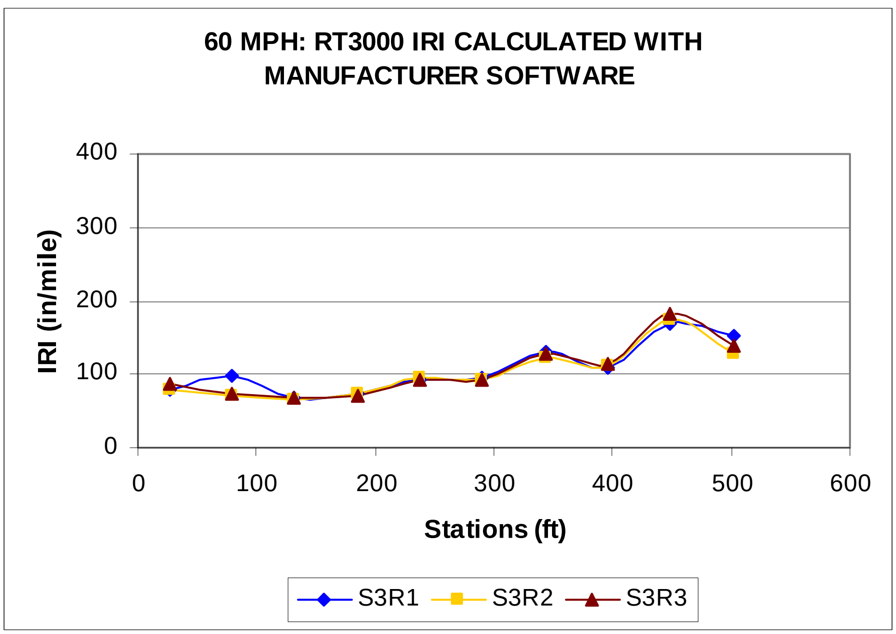


Figure B176: IRI, Route 195, Smooth, Section 3, Right Wheel Path

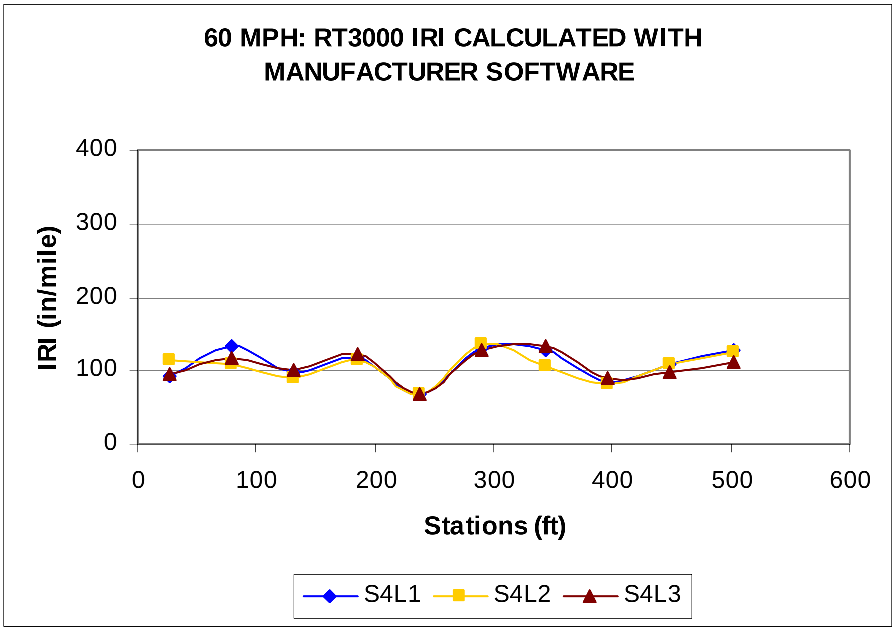


Figure B177: IRI, Route 195, Smooth, Section 4, Left Wheel Path

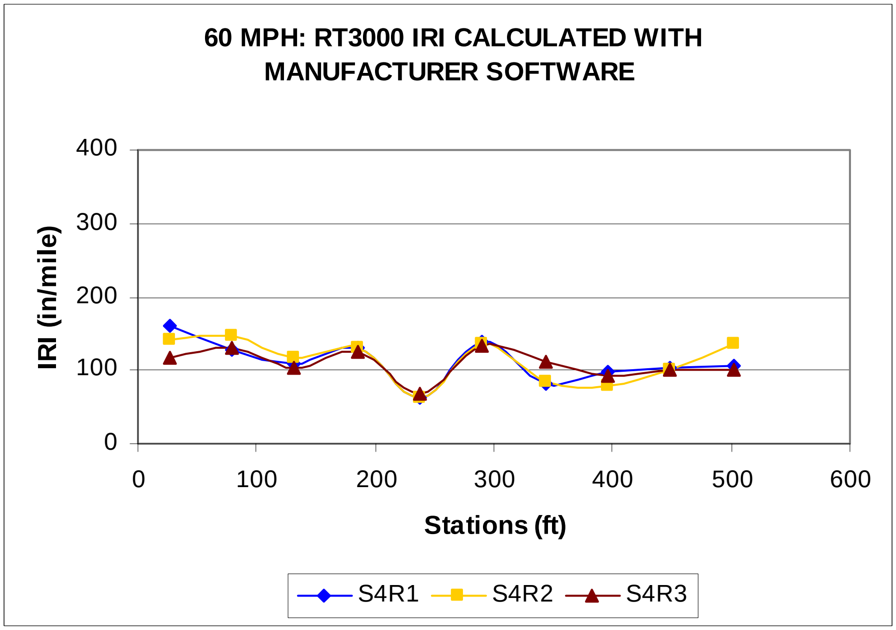


Figure B178: IRI, Route 195, Smooth, Section 4, Right Wheel Path

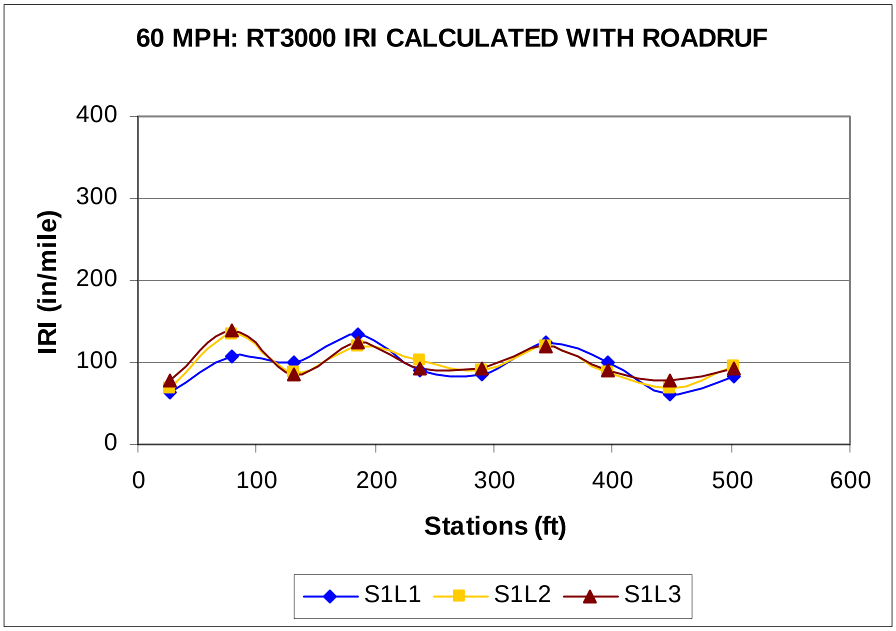


Figure B179: IRI, Route 195, Smooth, Section 1, Left Wheel Path

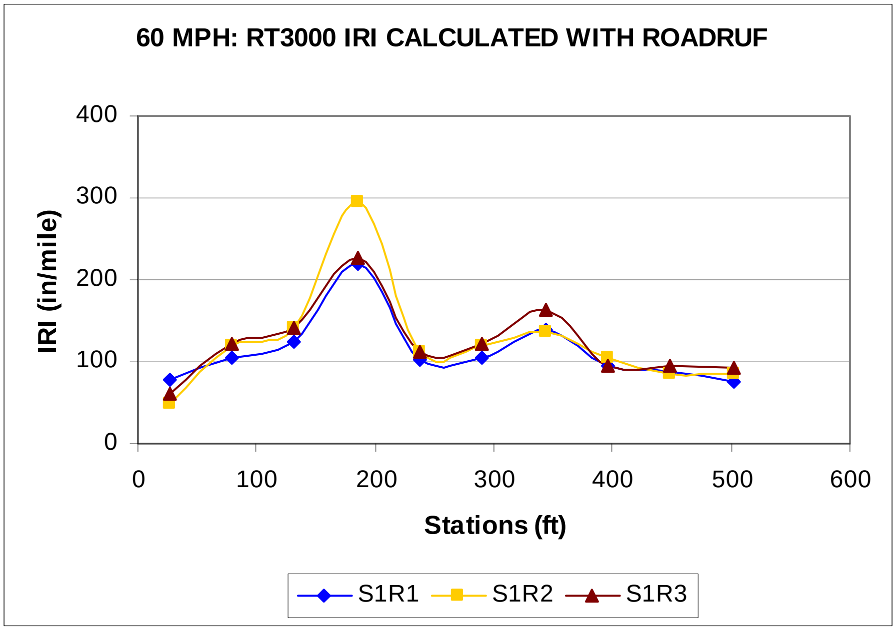


Figure B180: IRI, Route 195, Smooth, Section 1, Right Wheel Path

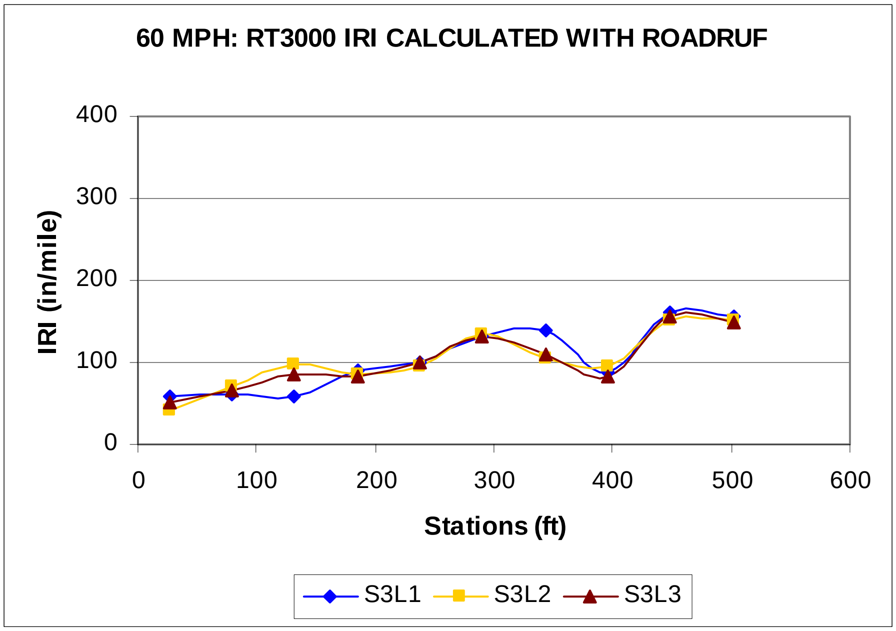


Figure B181: IRI, Route 195, Smooth, Section 3, Left Wheel Path

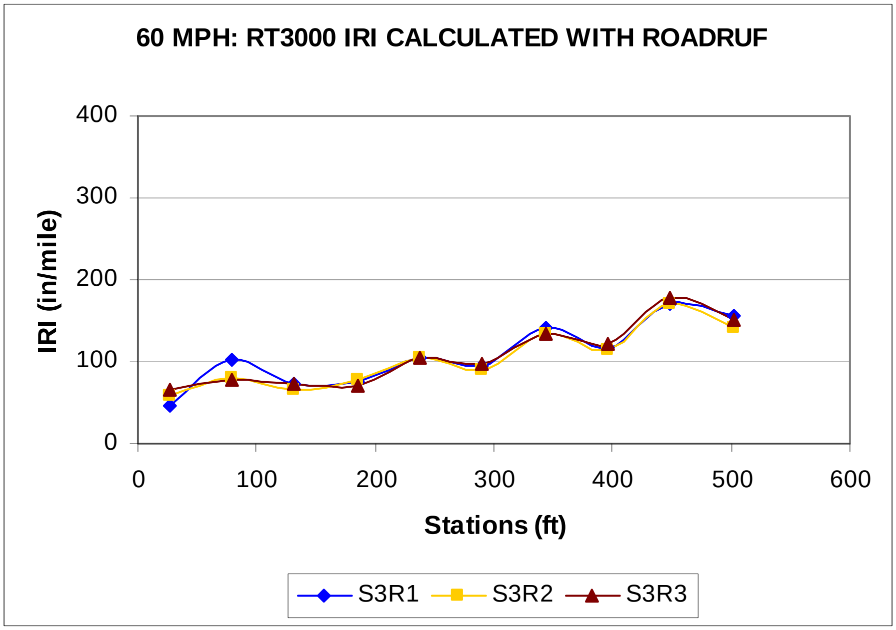


Figure B182: IRI, Route 195, Smooth, Section 3, Right Wheel Path

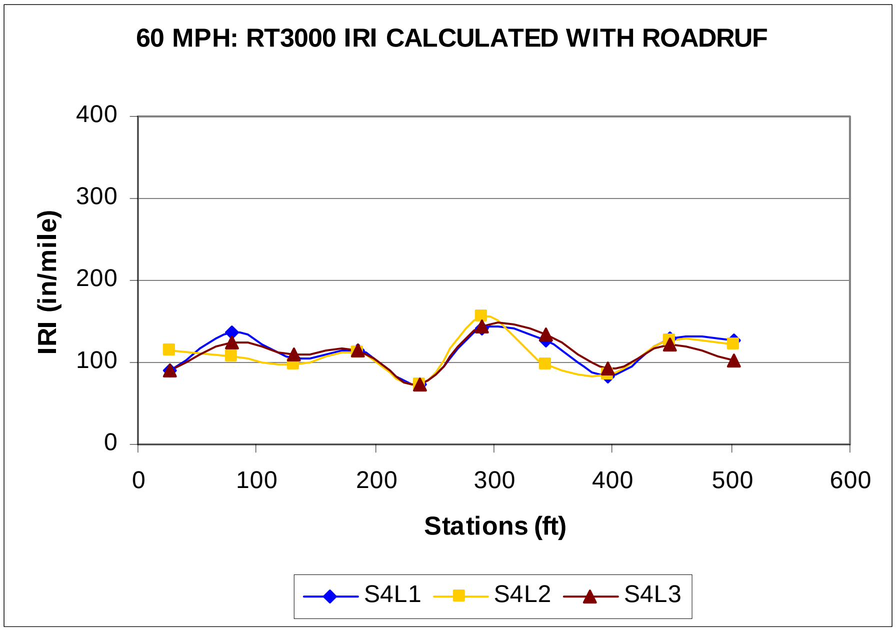


Figure B183: IRI, Route 195, Smooth, Section 4, Left Wheel Path

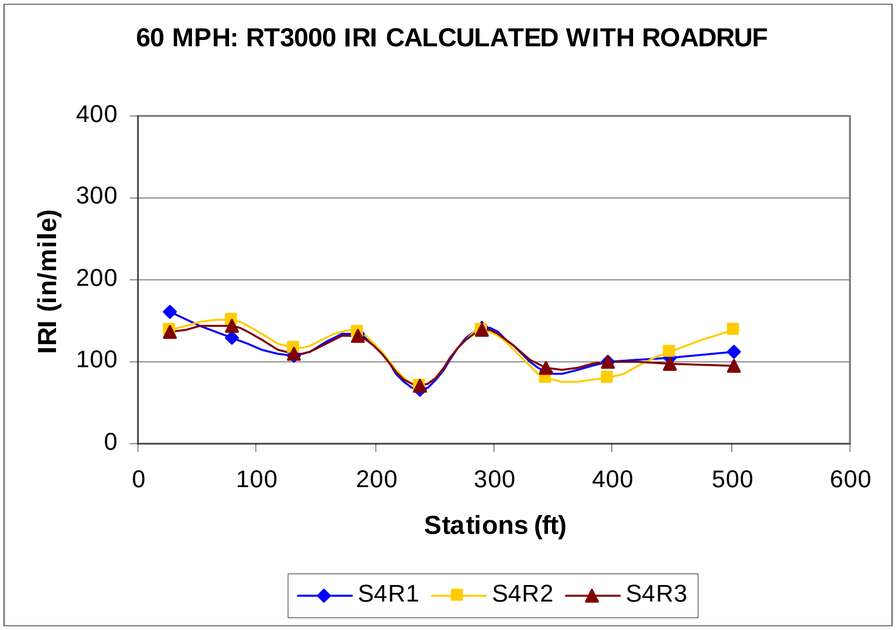


Figure B184: IRI, Route 195, Smooth, Section 4, Right Wheel Path

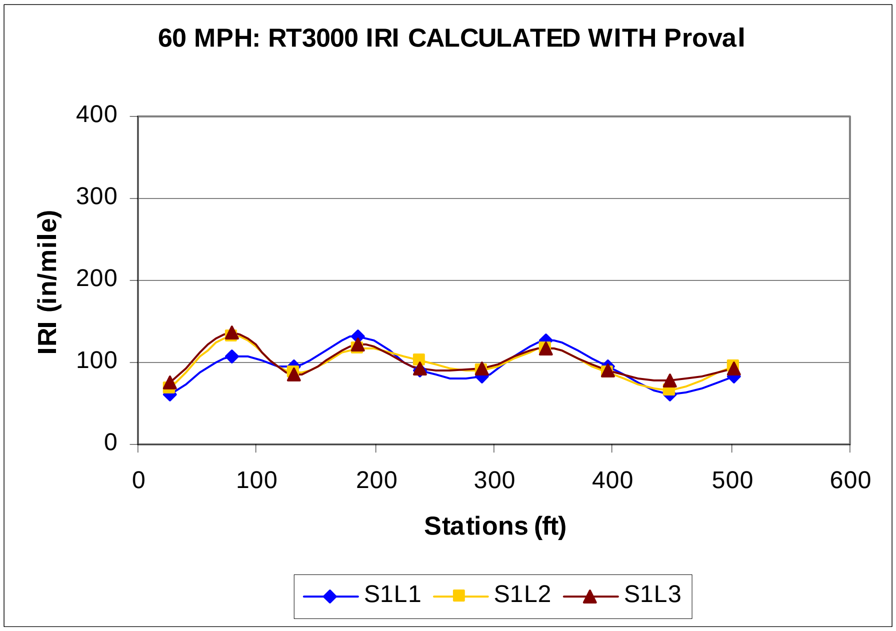


Figure B185: IRI, Route 195, Smooth, Section 1, Left Wheel Path

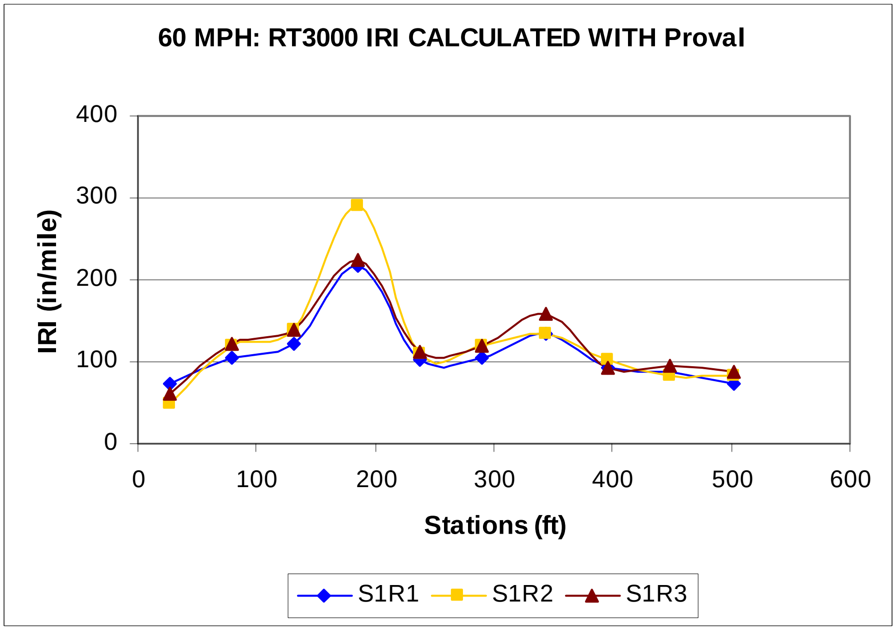


Figure B186: IRI, Route 195, Smooth, Section 1, Right Wheel Path

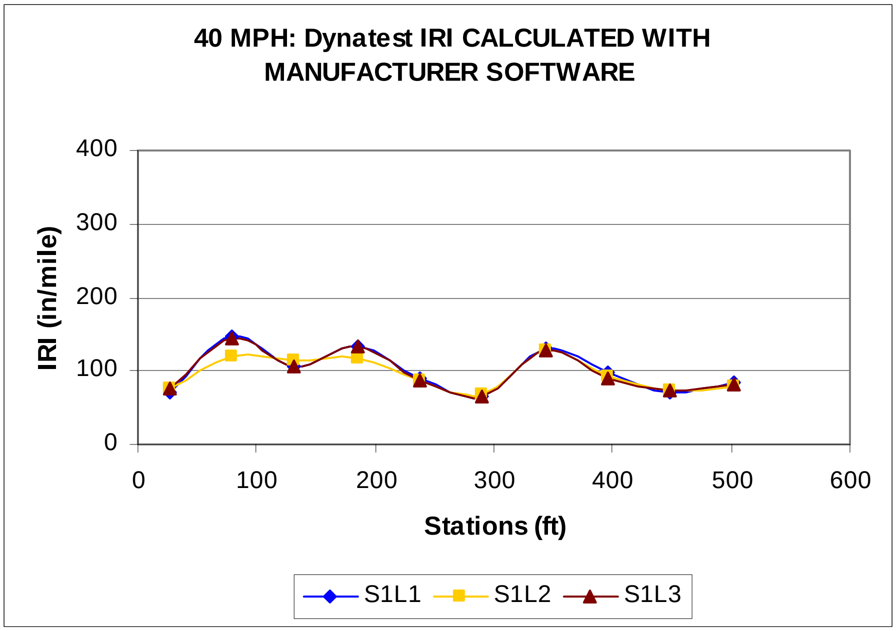


Figure B187: IRI, Route 195, Smooth, Section 1, Left Wheel Path

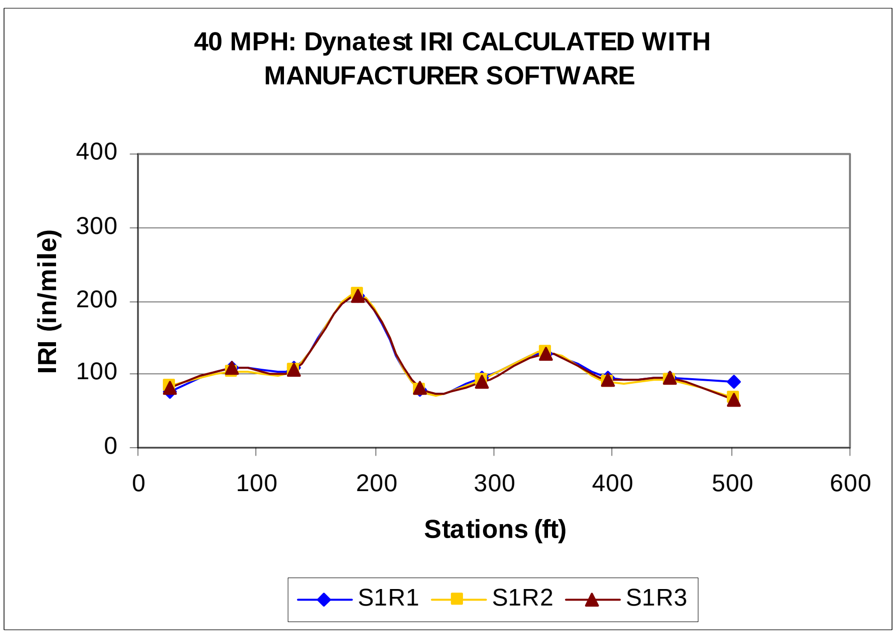


Figure B188: IRI, Route 195, Smooth, Section 1, Right Wheel Path

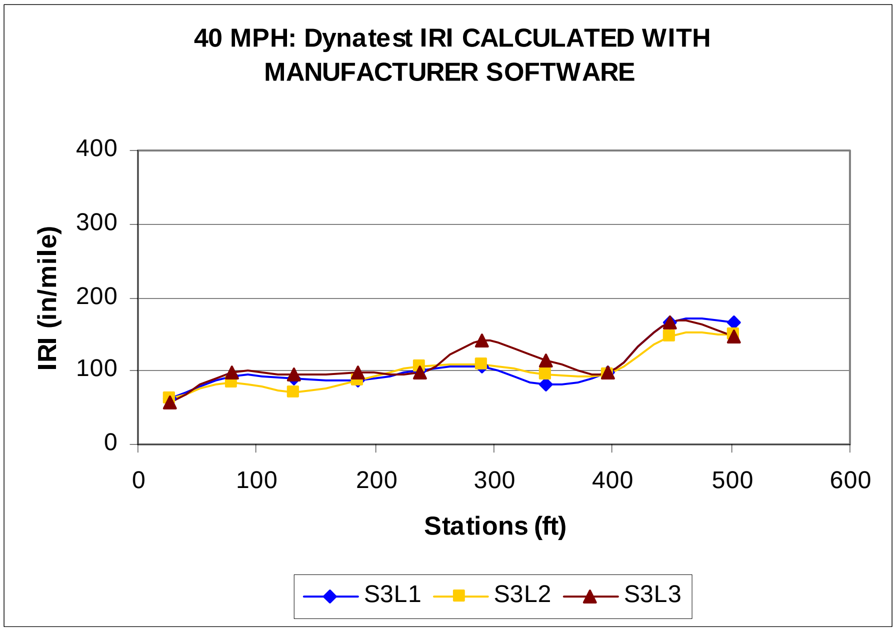


Figure B189: IRI, Route 195, Smooth, Section 3, Left Wheel Path

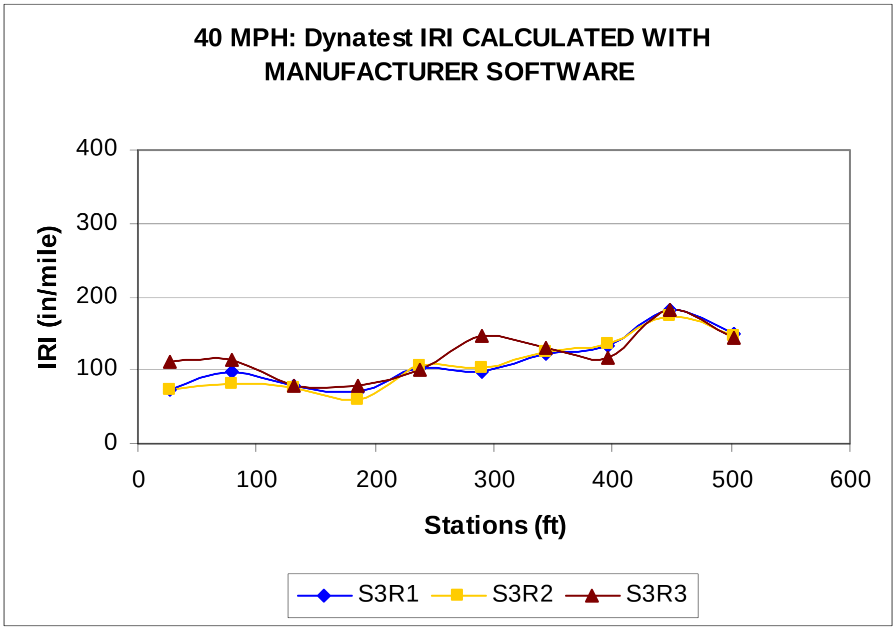


Figure B190: IRI, Route 195, Smooth, Section 3, Right Wheel Path

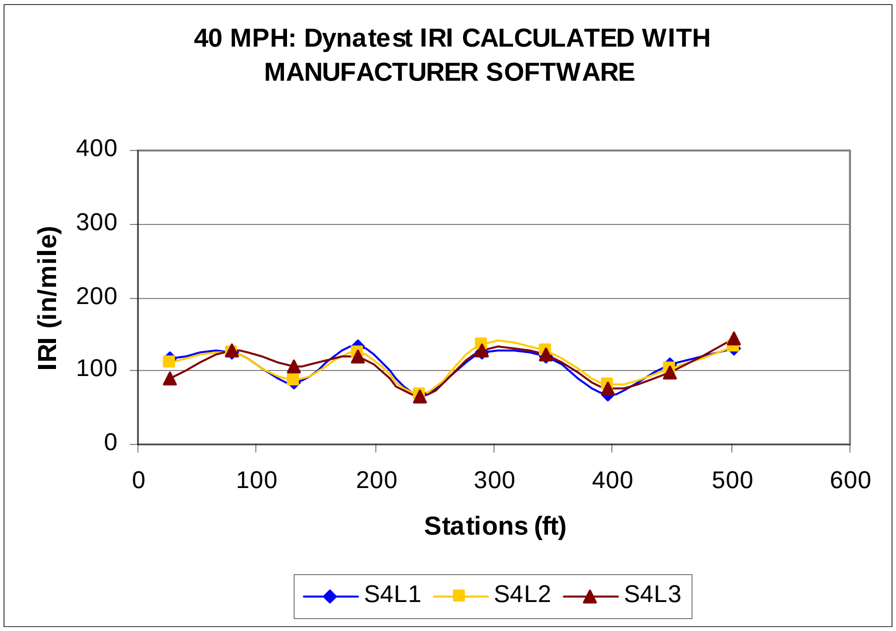


Figure B191: IRI, Route 195, Smooth, Section 4, Left Wheel Path

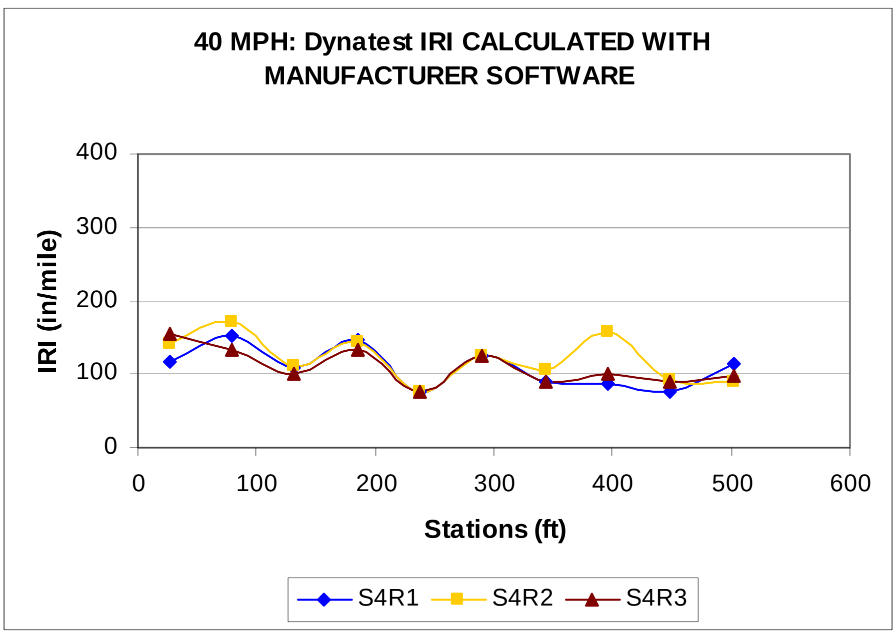


Figure B192: IRI, Route 195, Smooth, Section 4, Right Wheel Path

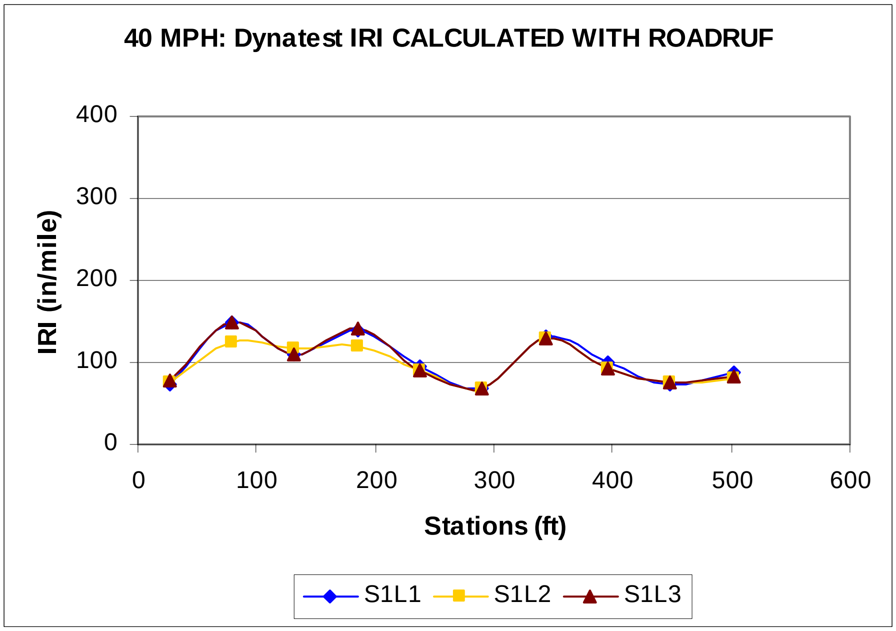


Figure B193: IRI, Route 195, Smooth, Section 1, Left Wheel Path

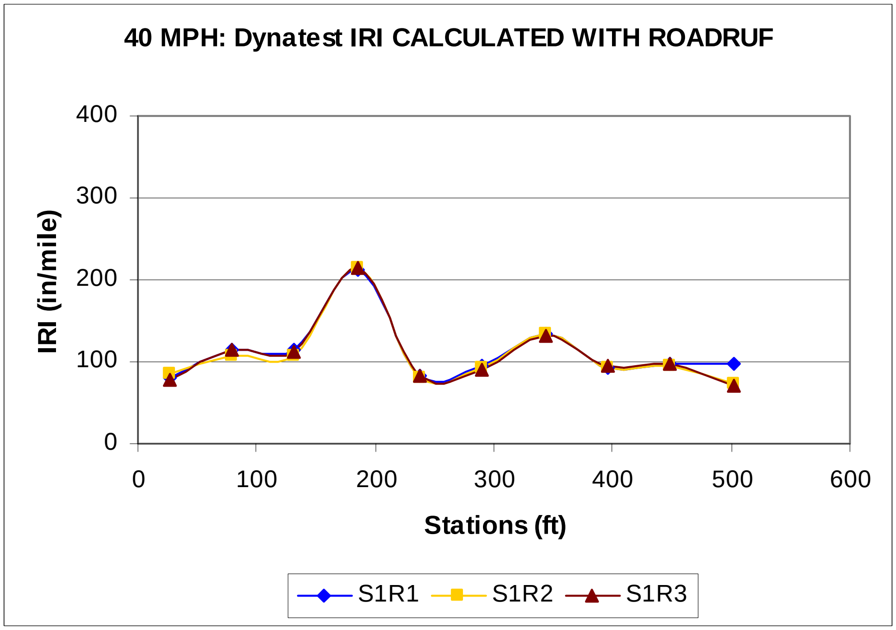


Figure B194: IRI, Route 195, Smooth, Section 1, Right Wheel Path

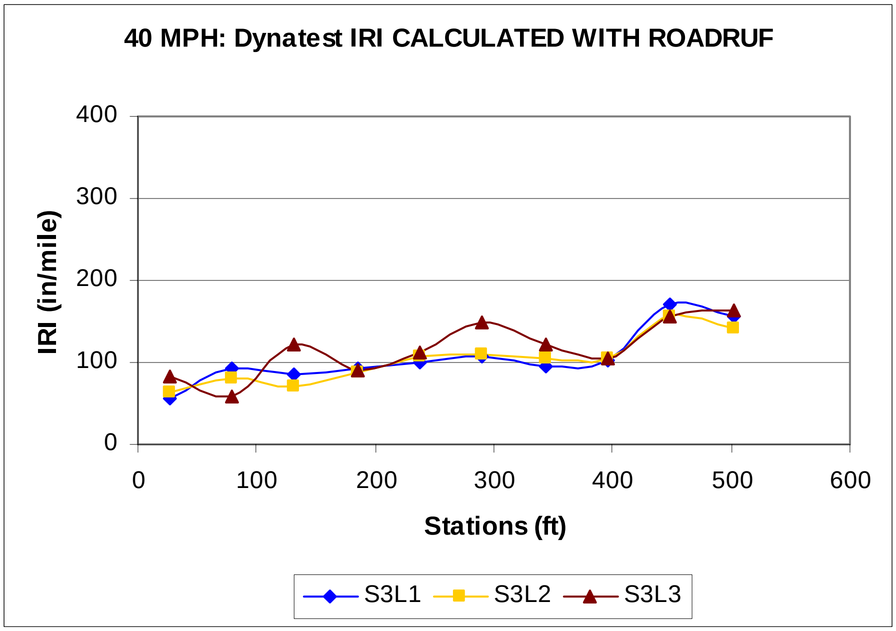


Figure B195: IRI, Route 195, Smooth, Section 3, Left Wheel Path

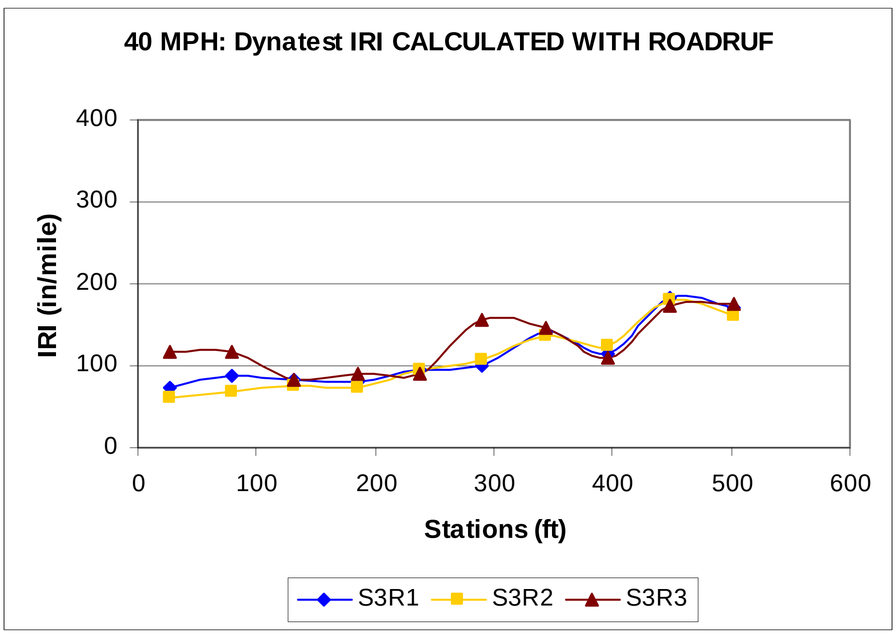


Figure B196: IRI, Route 195, Smooth, Section 3, Right Wheel Path

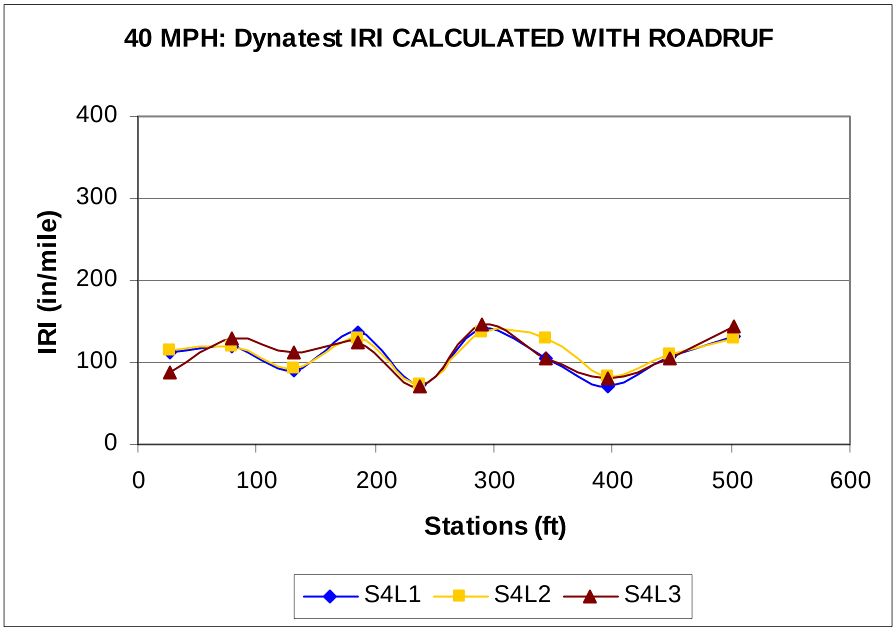


Figure B197: IRI, Route 195, Smooth, Section 4, Left Wheel Path

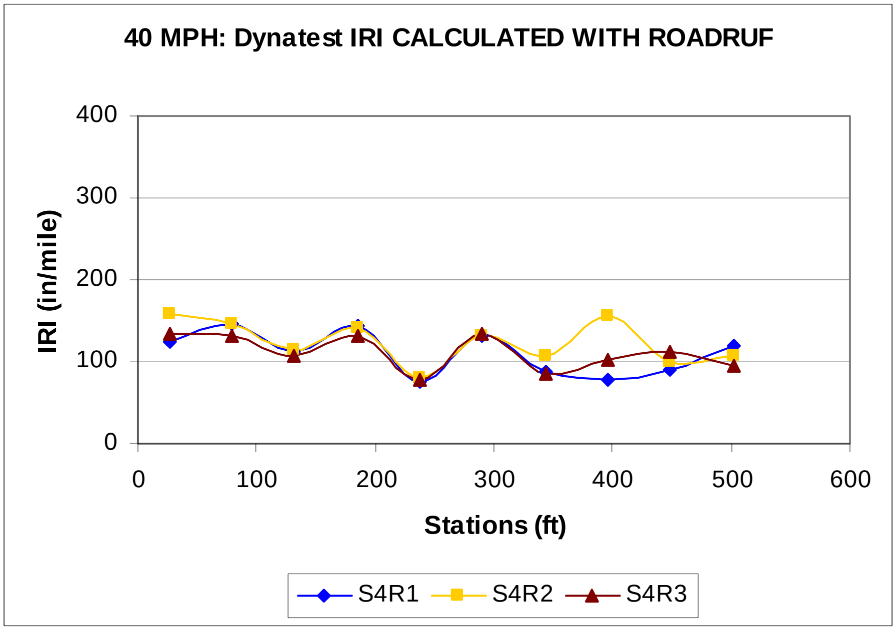


Figure B198: IRI, Route 195, Smooth, Section 4, Right Wheel Path

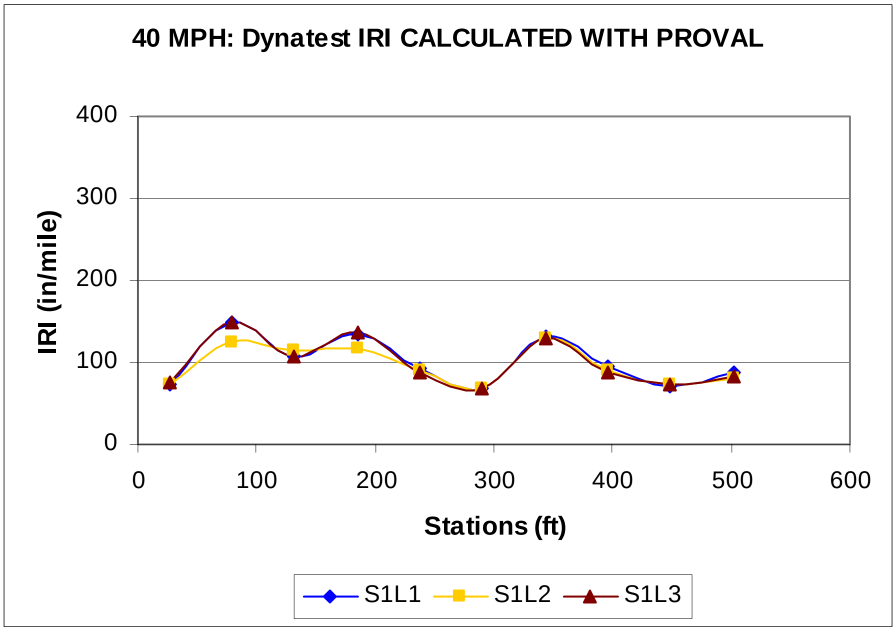


Figure B199: IRI, Route 195, Smooth, Section 1, Left Wheel Path

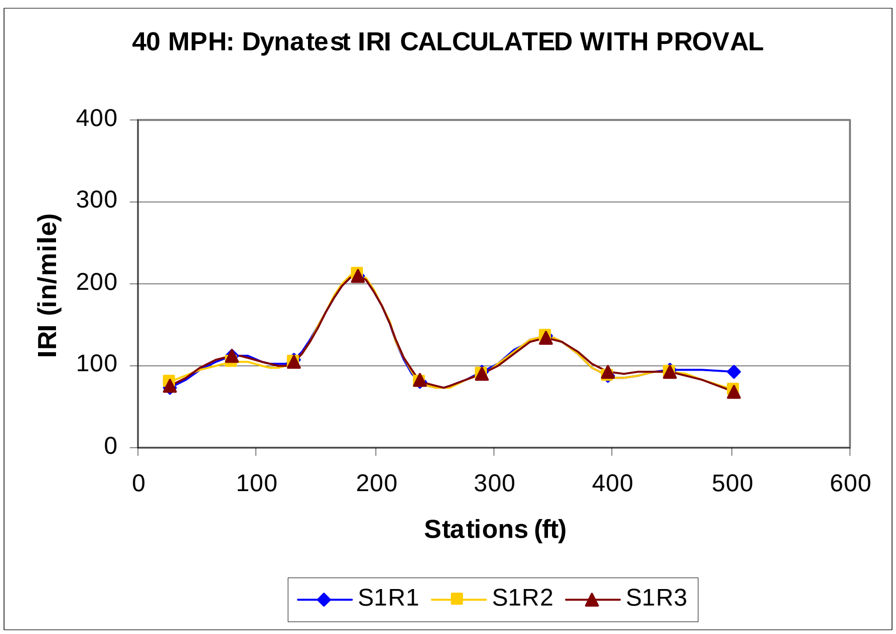


Figure B200: IRI, Route 195, Smooth, Section 1, Right Wheel Path

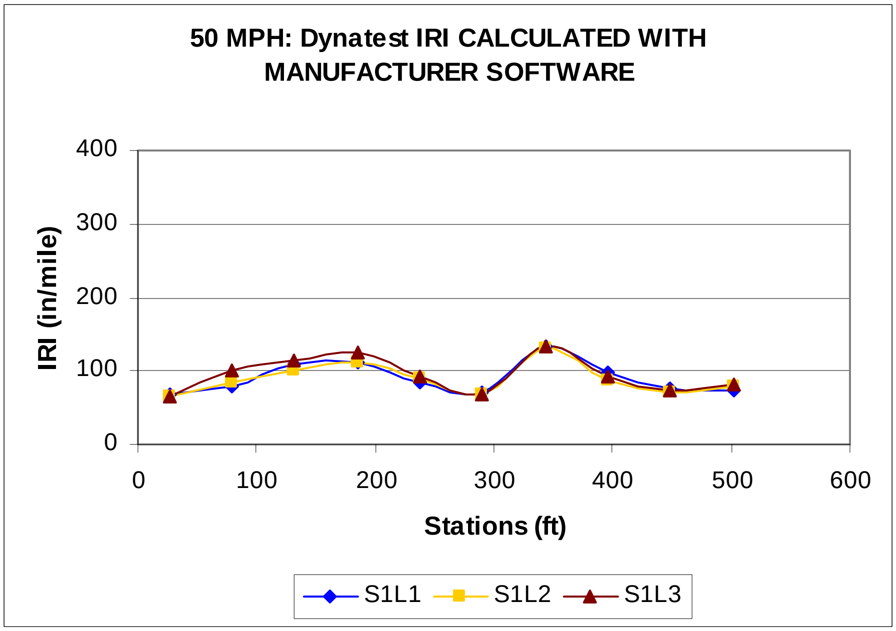


Figure B201: IRI, Route 195, Smooth, Section 1, Left Wheel Path

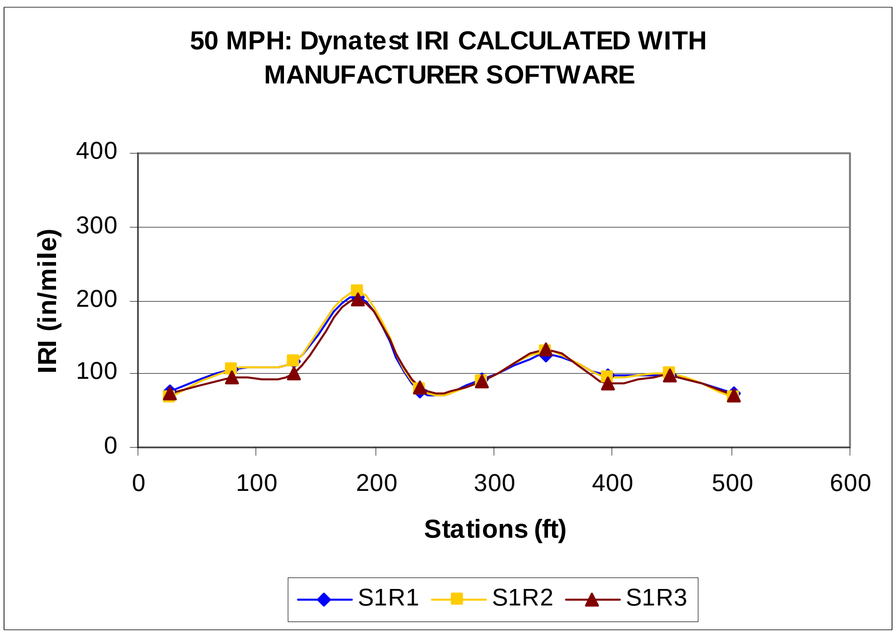


Figure B202: IRI, Route 195, Smooth, Section 1, Right Wheel Path

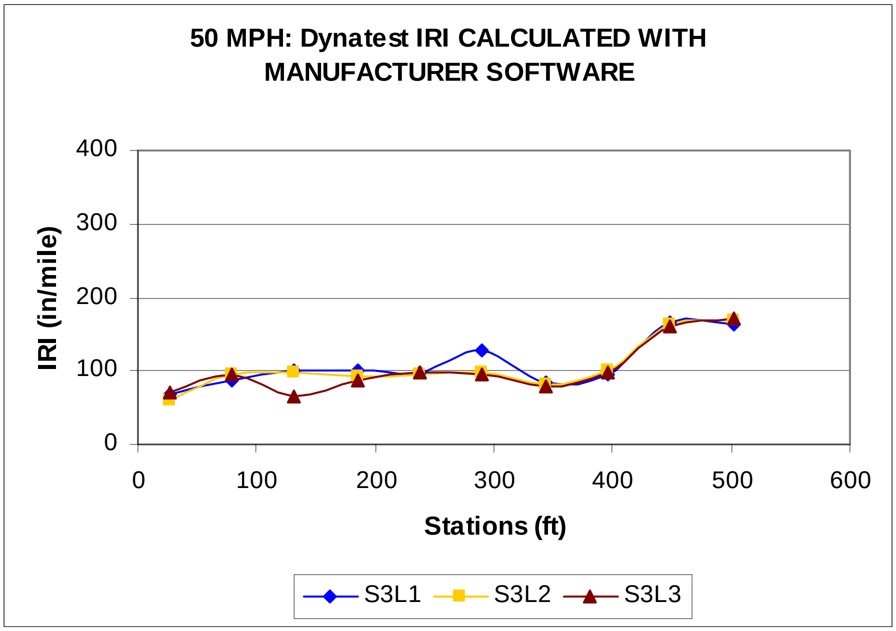


Figure B203: IRI, Route 195, Smooth, Section 3, Left Wheel Path

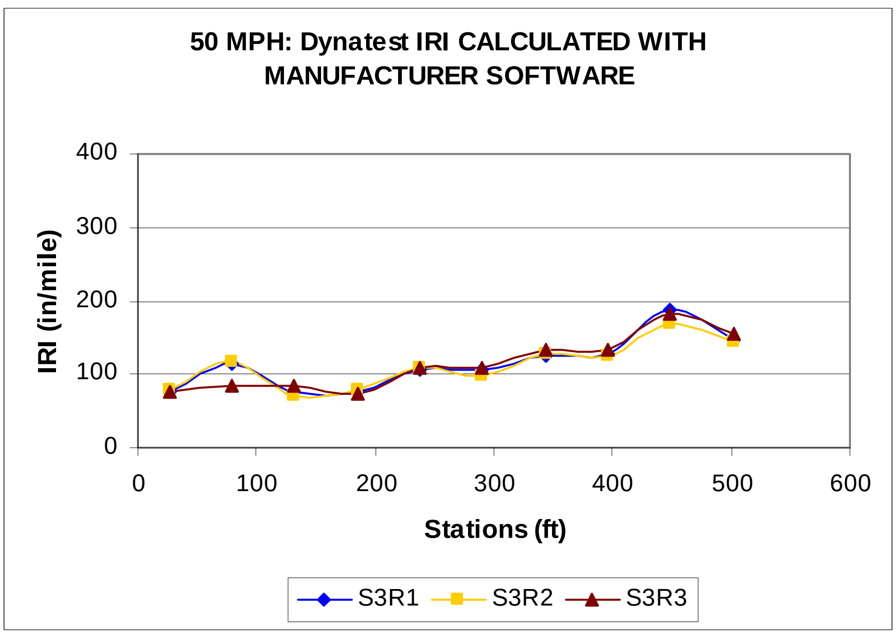


Figure B204: IRI, Route 195, Smooth, Section 3, Right Wheel Path

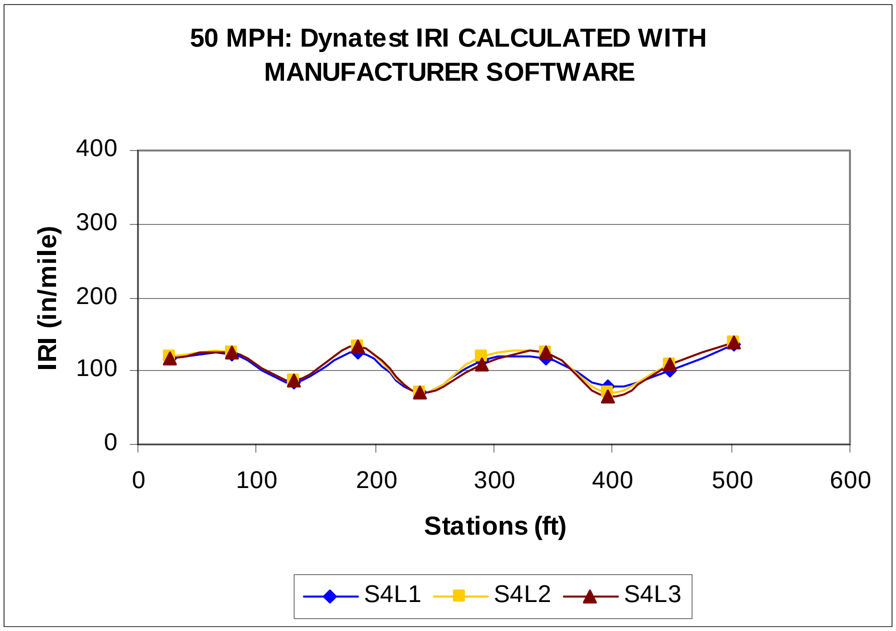


Figure B205: IRI, Route 195, Smooth, Section 4, Left Wheel Path

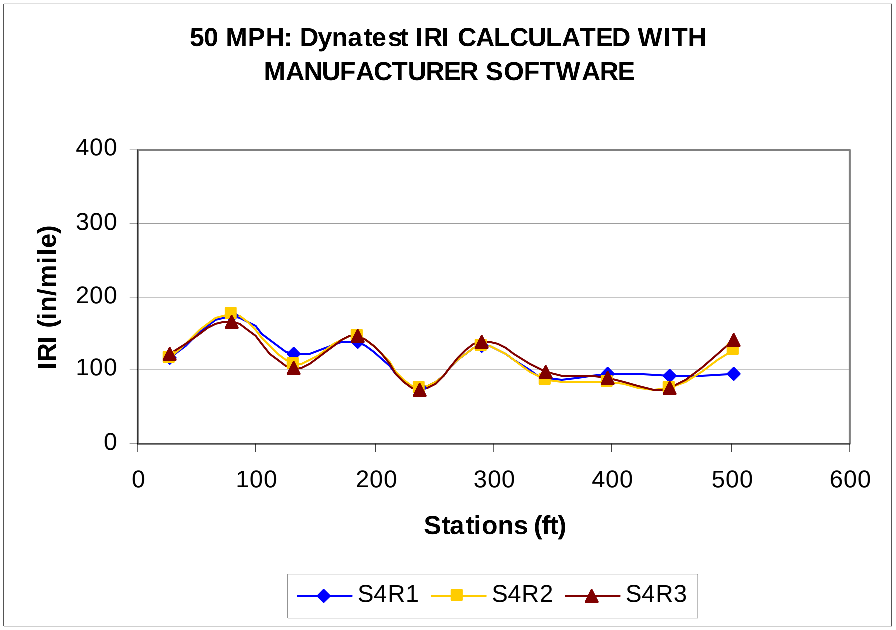


Figure B206: IRI, Route 195, Smooth, Section 4, Right Wheel Path

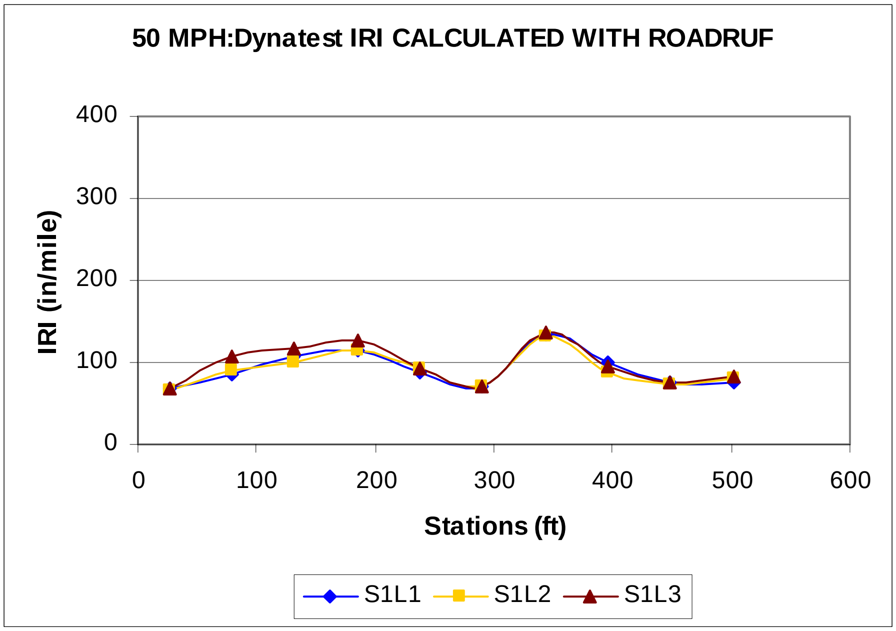


Figure B207: IRI, Route 195, Smooth, Section 1, Left Wheel Path

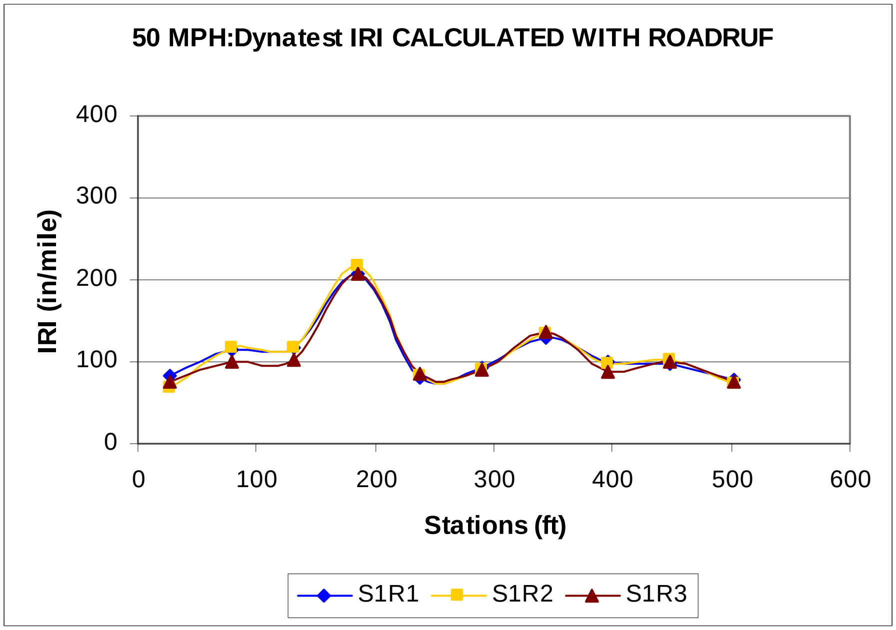


Figure B208: IRI, Route 195, Smooth, Section 1, Right Wheel Path

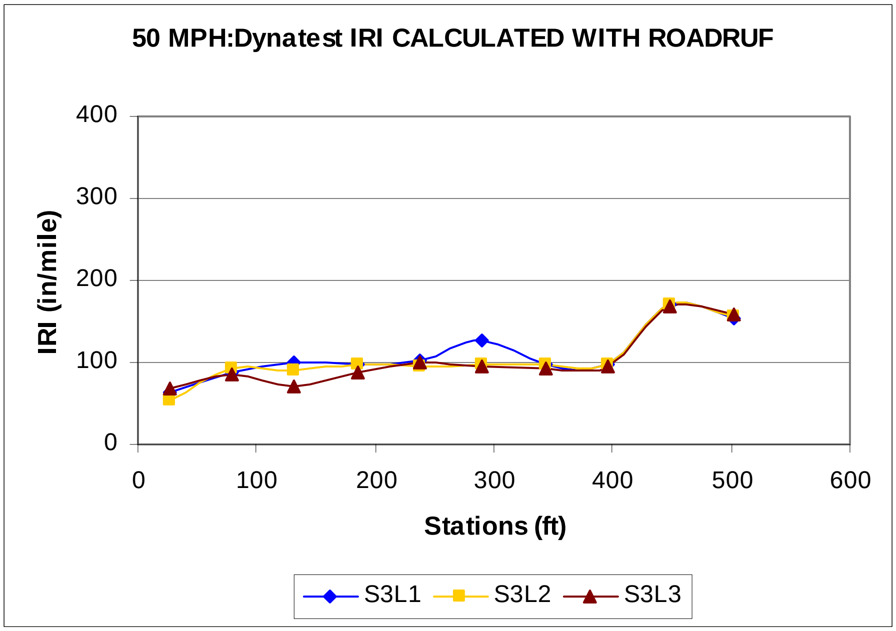


Figure B209: IRI, Route 195, Smooth, Section 3, Left Wheel Path

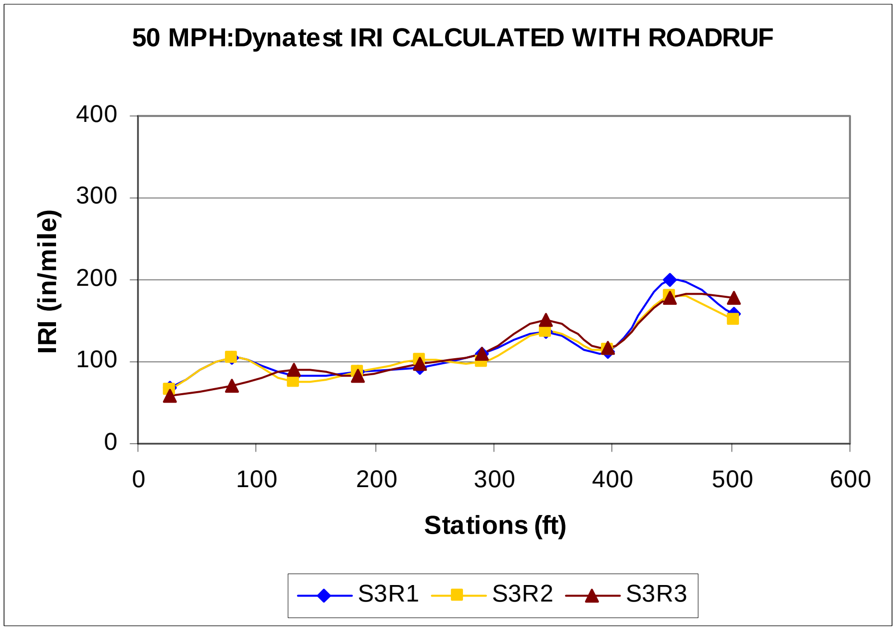


Figure B210: IRI, Route 195, Smooth, Section 3, Right Wheel Path

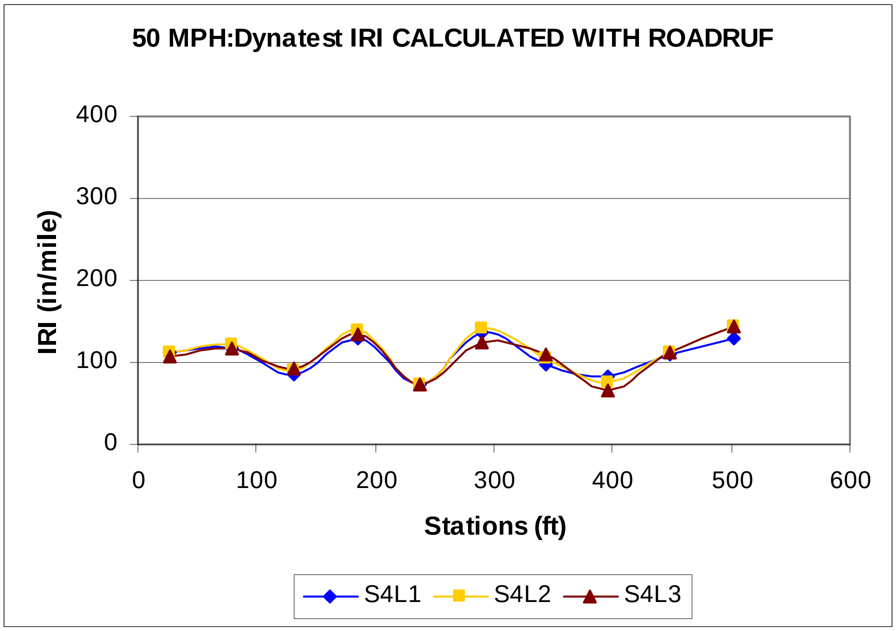


Figure B211: IRI, Route 195, Smooth, Section 4, Left Wheel Path

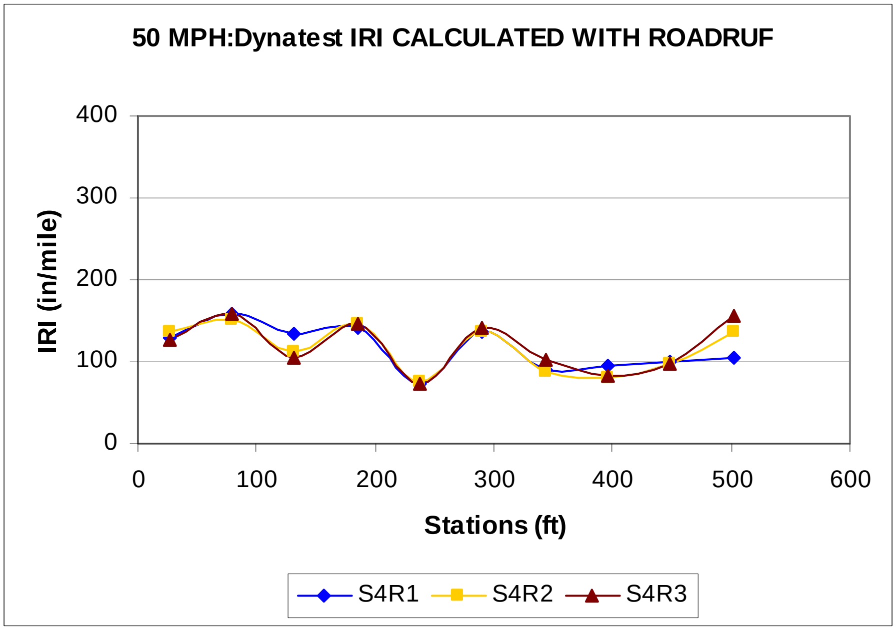


Figure B212: IRI, Route 195, Smooth, Section 4, Right Wheel Path

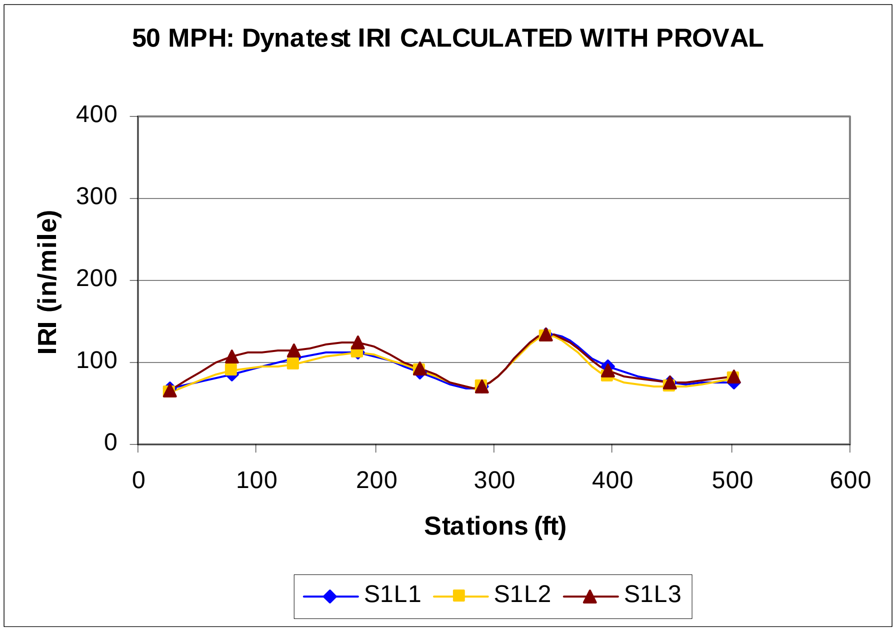


Figure B213: IRI, Route 195, Smooth, Section 1, Left Wheel Path

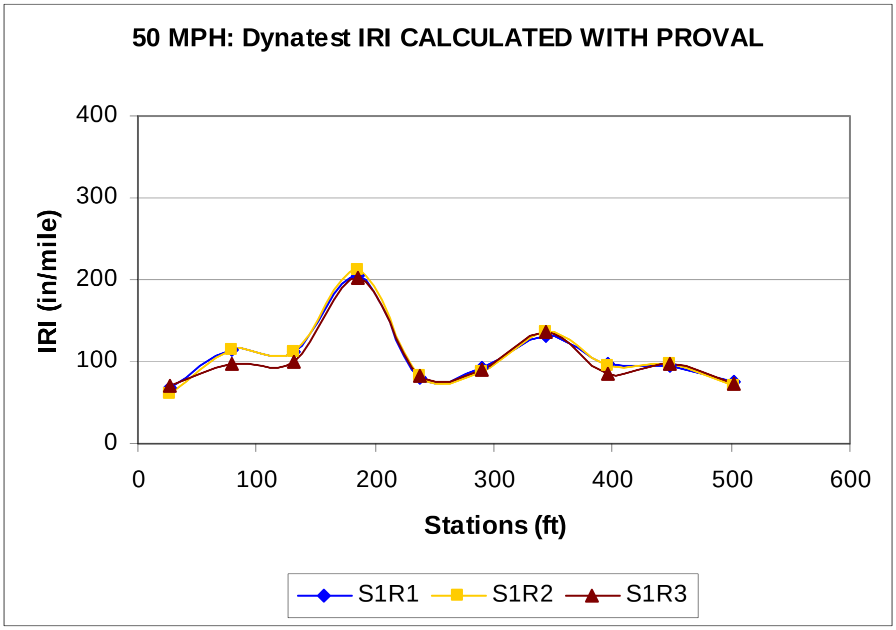


Figure B214: IRI, Route 195, Smooth, Section 1, Right Wheel Path

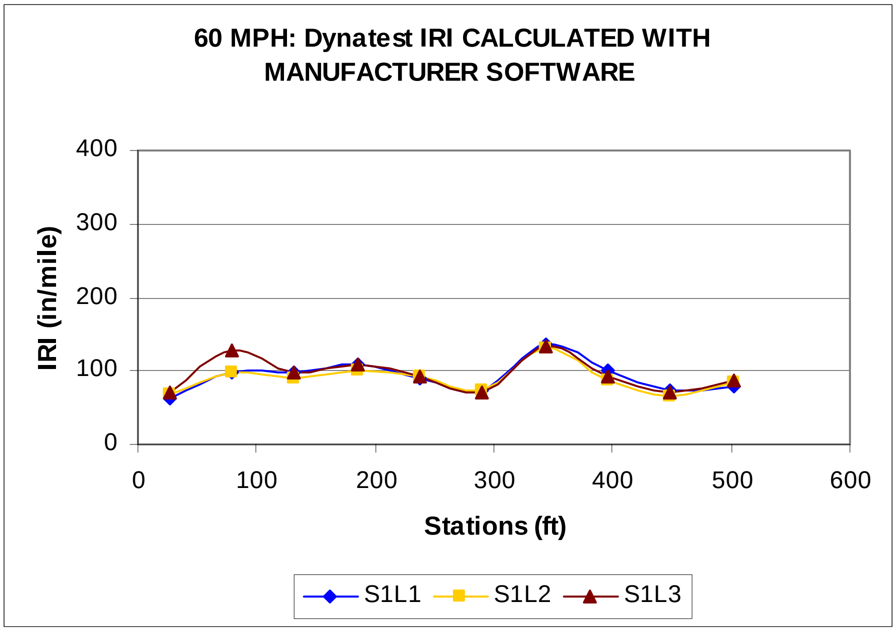


Figure B215: IRI, Route 195, Smooth, Section 1, Left Wheel Path

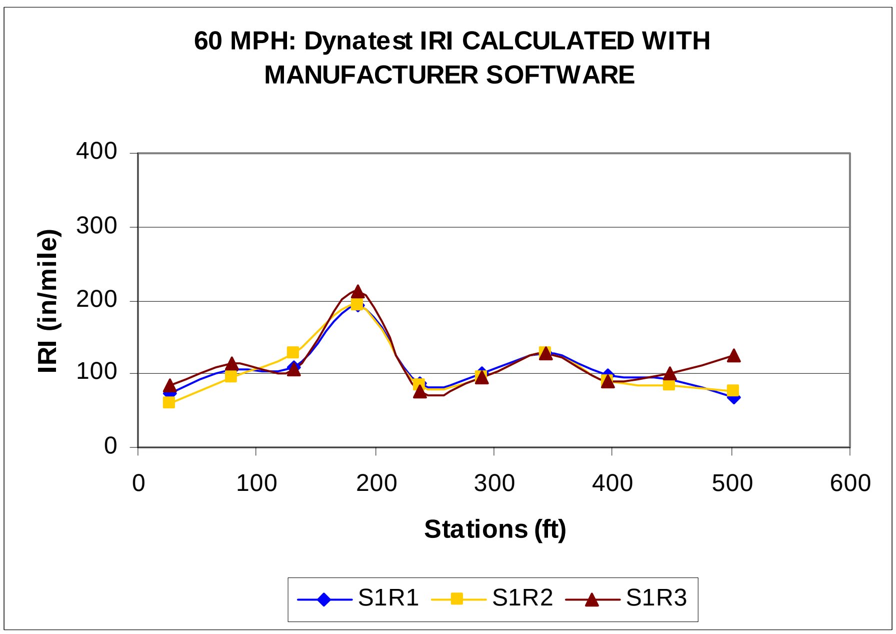


Figure B216: IRI, Route 195, Smooth, Section 1, Right Wheel Path

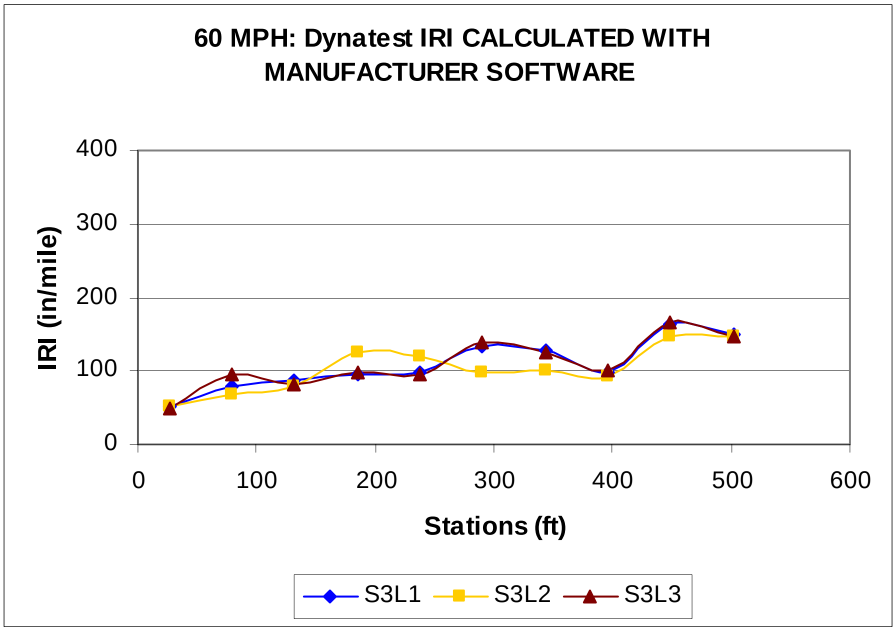


Figure B217: IRI, Route 195, Smooth, Section 3, Left Wheel Path

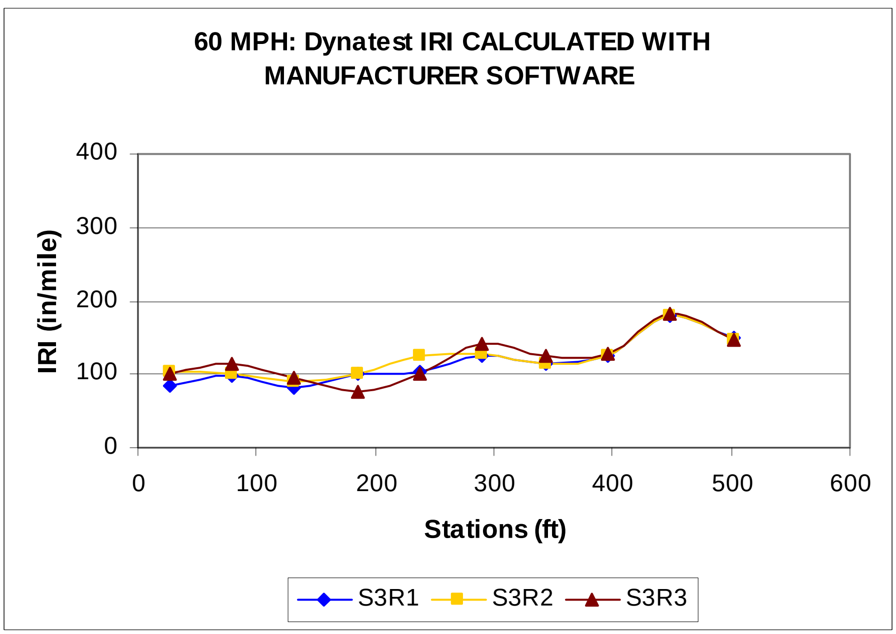


Figure B218: IRI, Route 195, Smooth, Section 3, Right Wheel Path

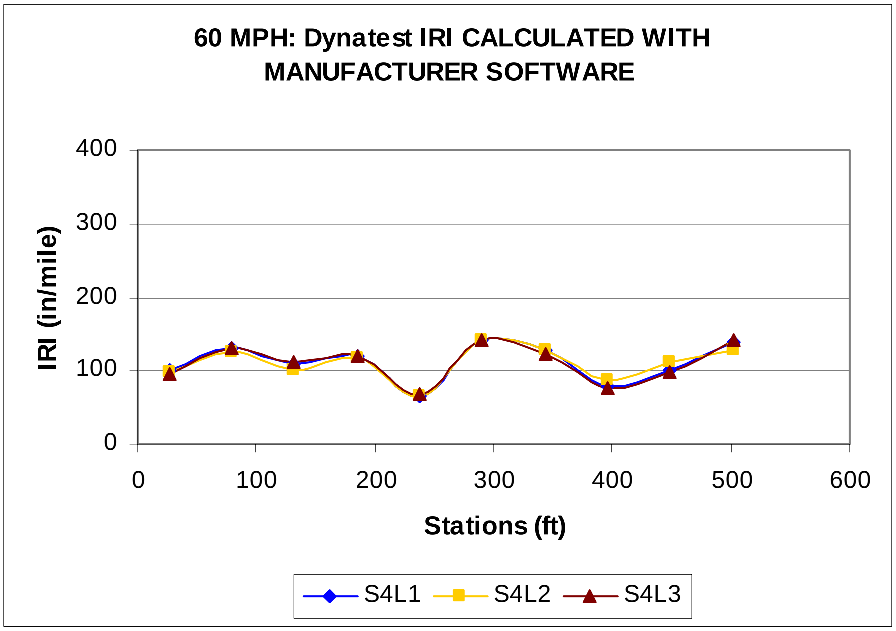


Figure B219: IRI, Route 195, Smooth, Section 4, Left Wheel Path

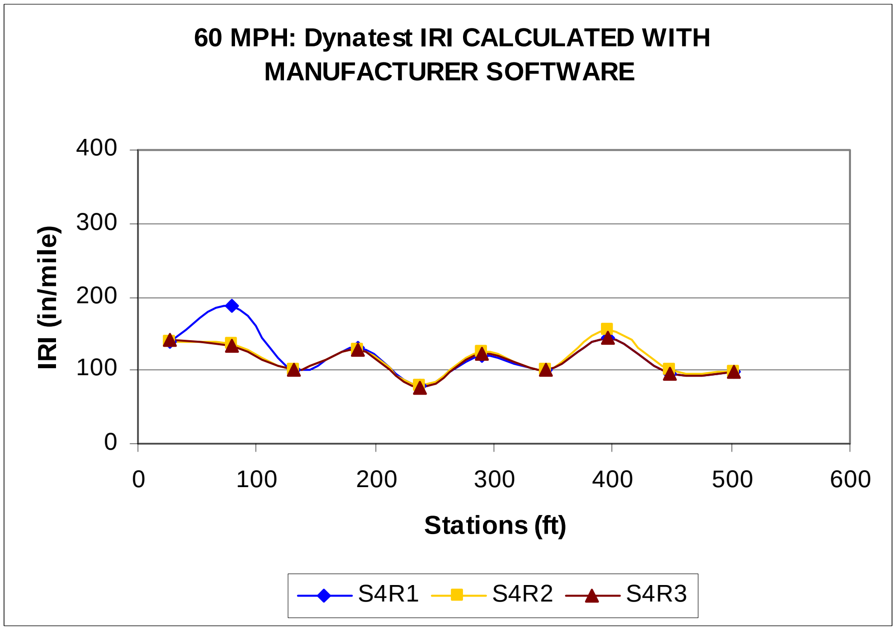


Figure B220: IRI, Route 195, Smooth, Section 4, Right Wheel Path

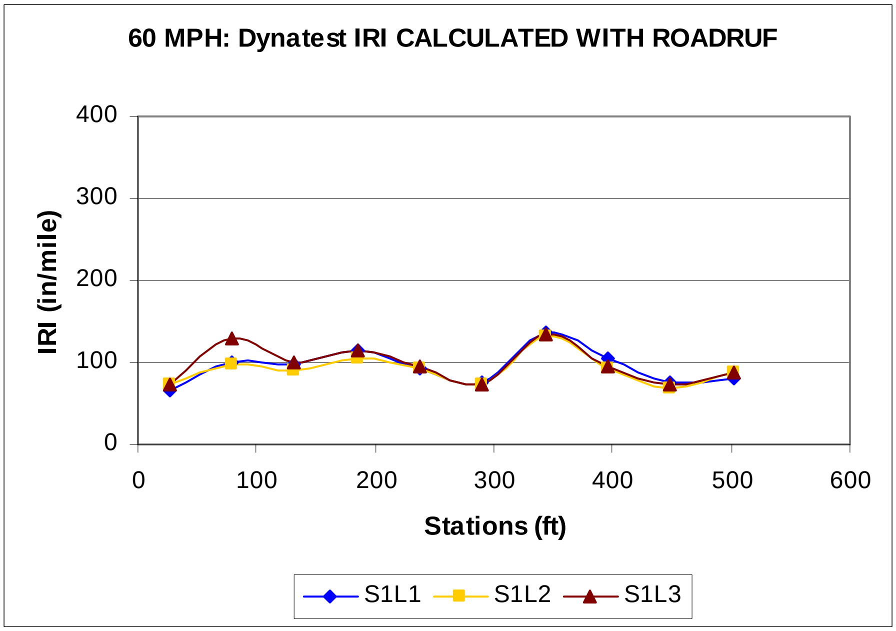


Figure B221: IRI, Route 195, Smooth, Section 1, Left Wheel Path

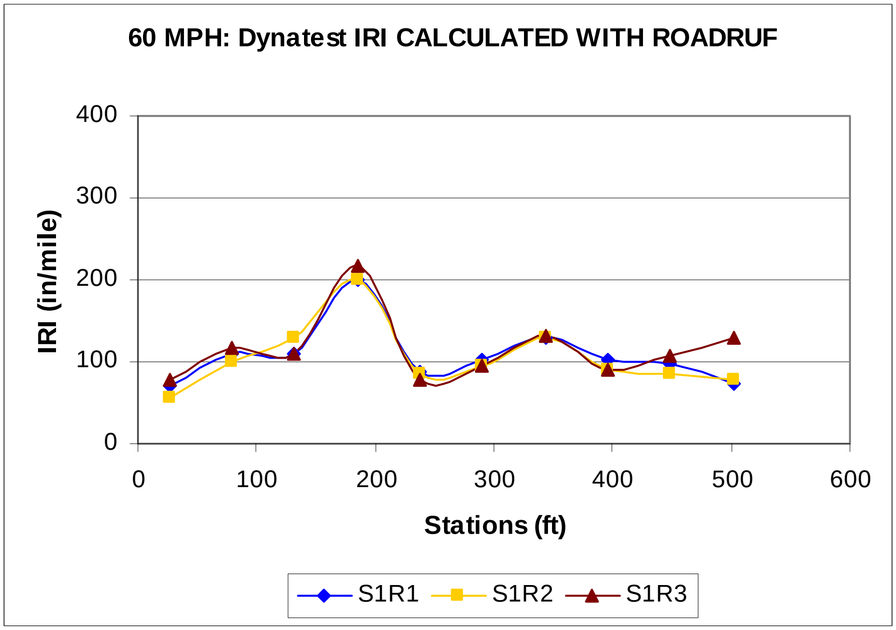


Figure B222: IRI, Route 195, Smooth, Section 1, Right Wheel Path

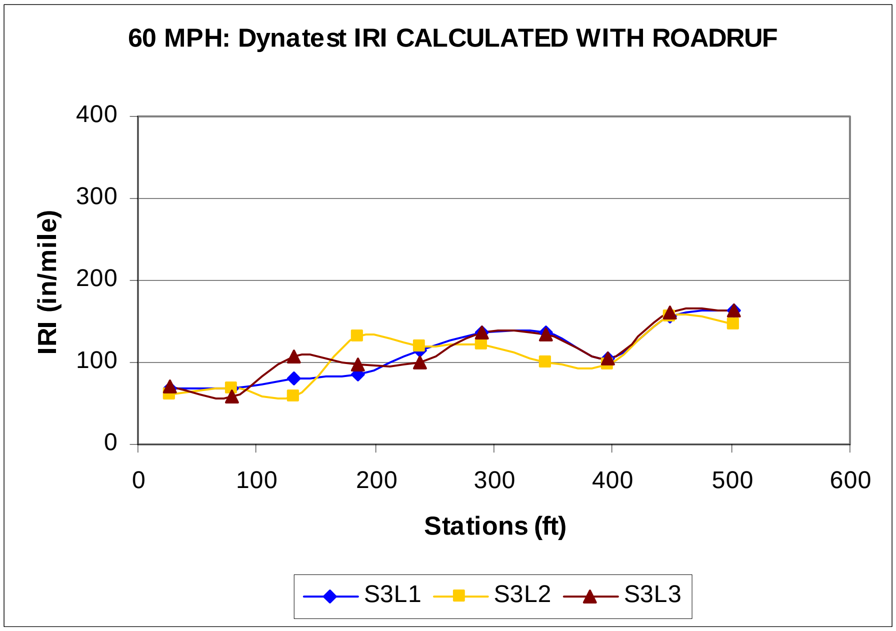


Figure B223: IRI, Route 195, Smooth, Section 3, Left Wheel Path

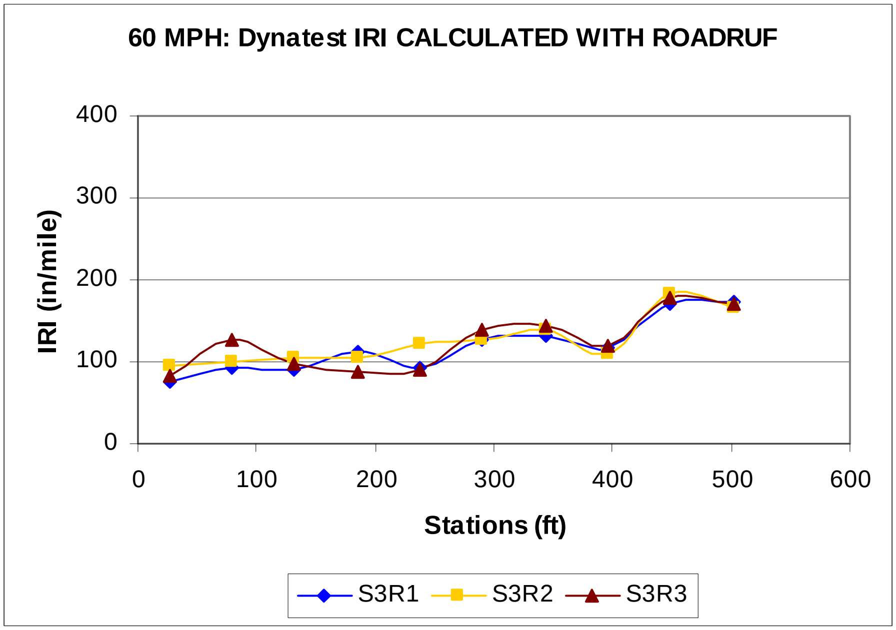


Figure B224: IRI, Route 195, Smooth, Section 3, Right Wheel Path

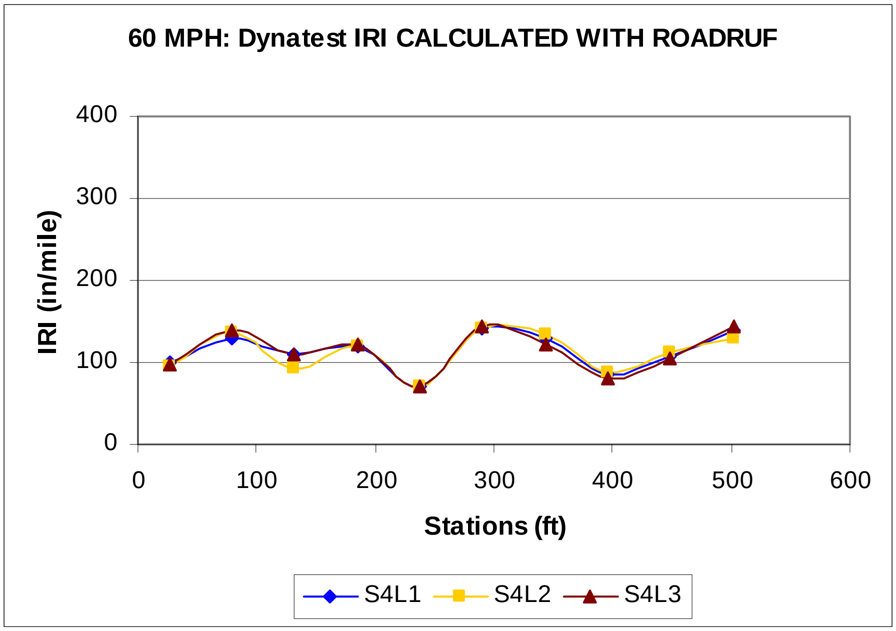


Figure B225: IRI, Route 195, Smooth, Section 4, Left Wheel Path

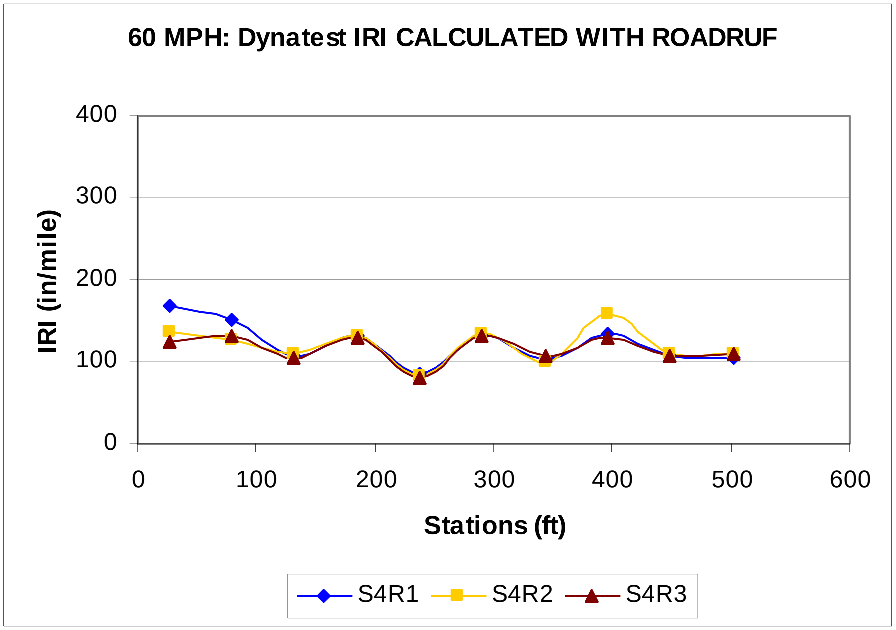


Figure B226: IRI, Route 195, Smooth, Section 4, Right Wheel Path

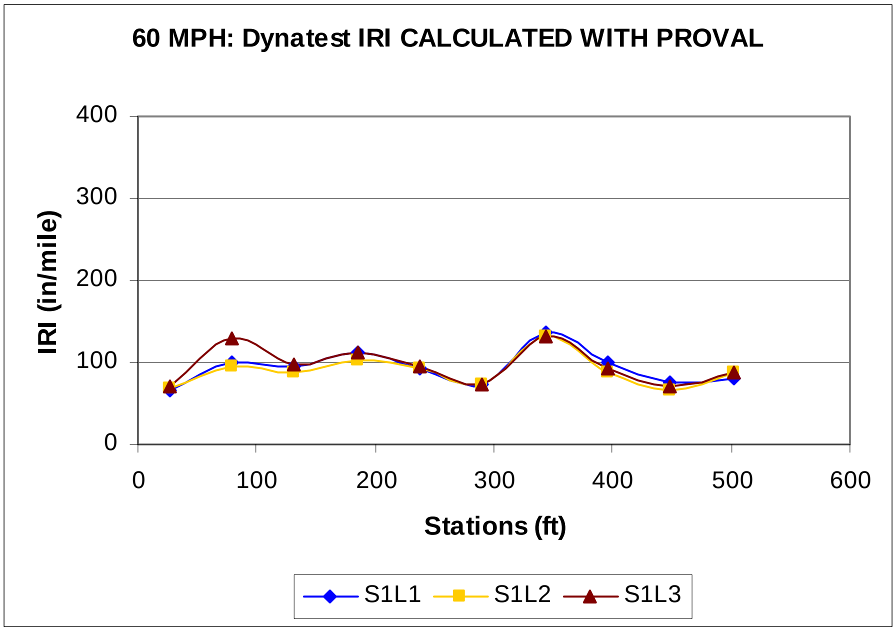


Figure B227: IRI, Route 195, Smooth, Section 1, Left Wheel Path

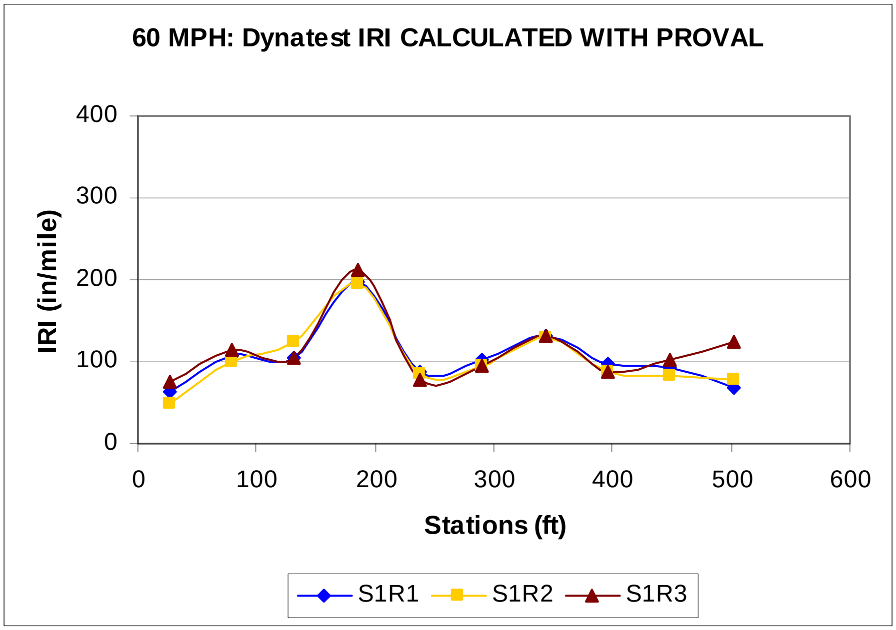


Figure B228: IRI, Route 195, Smooth, Section 1, Right Wheel Path

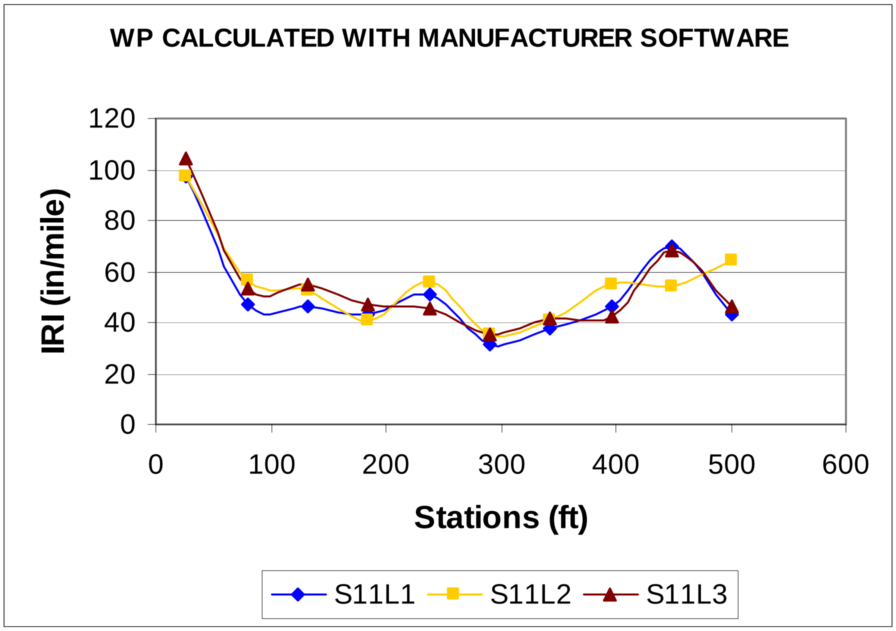


Figure B229: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

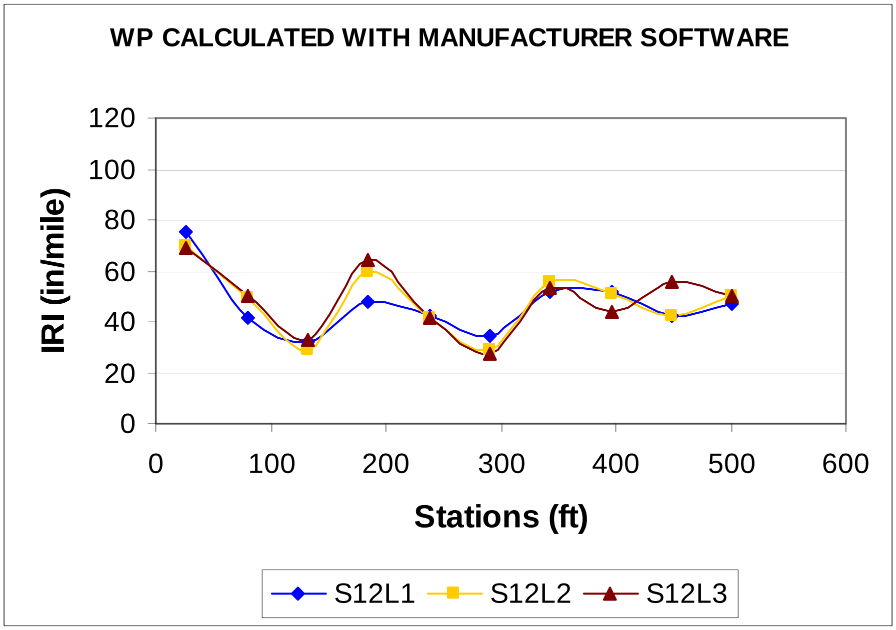


Figure B230: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

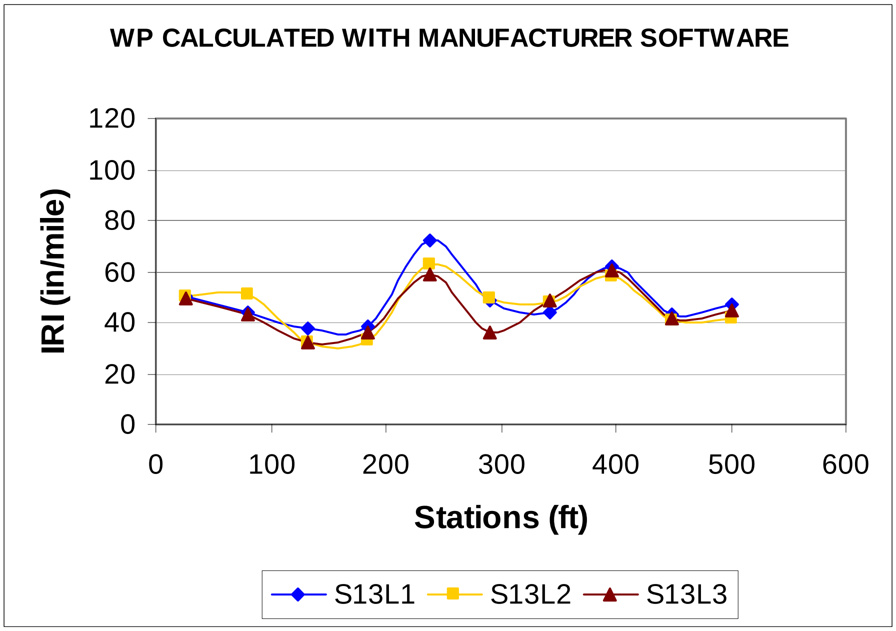


Figure B231: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

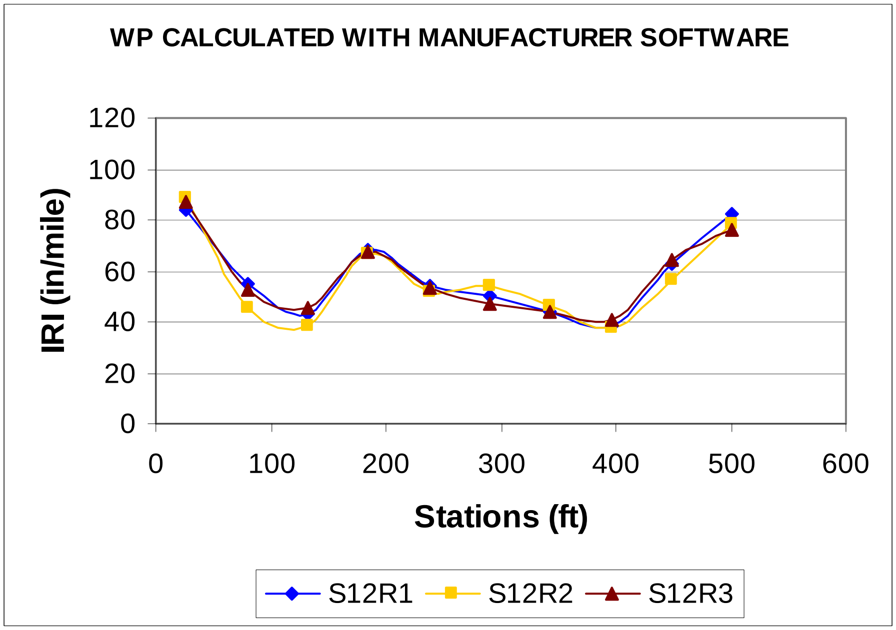


Figure B232: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

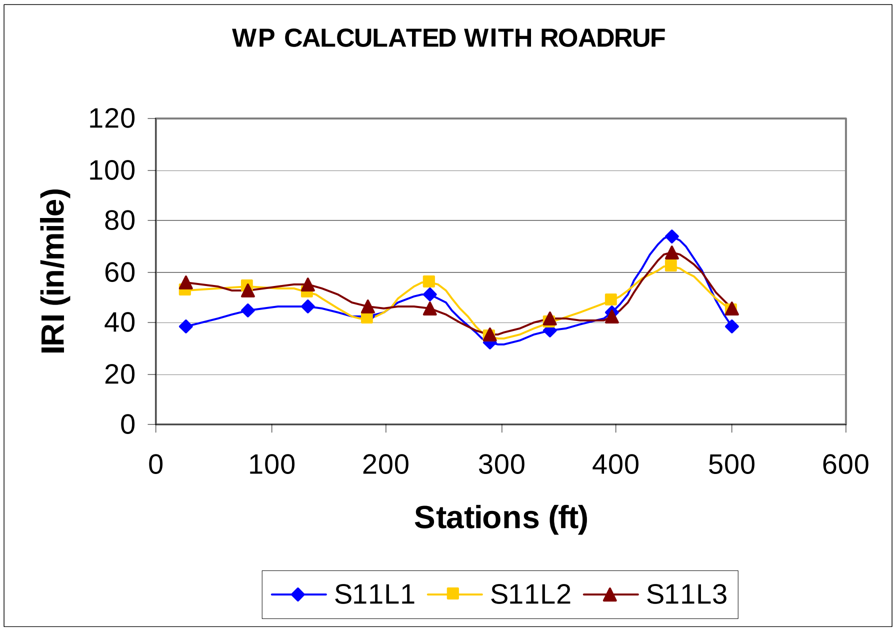


Figure B233: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

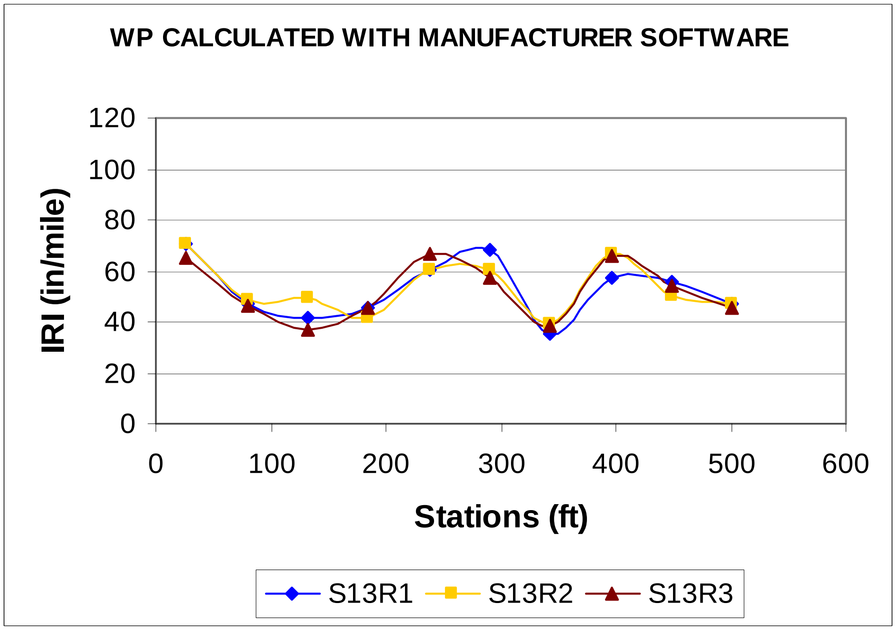


Figure B234: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

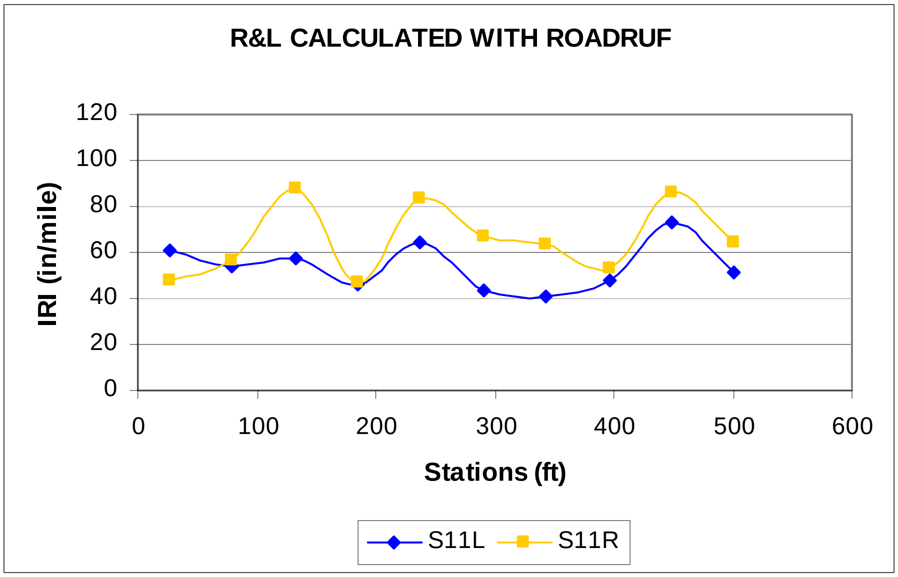


Figure B235: IRI, Route 55, Very Smooth, Section 11, Left and Right Wheel Path

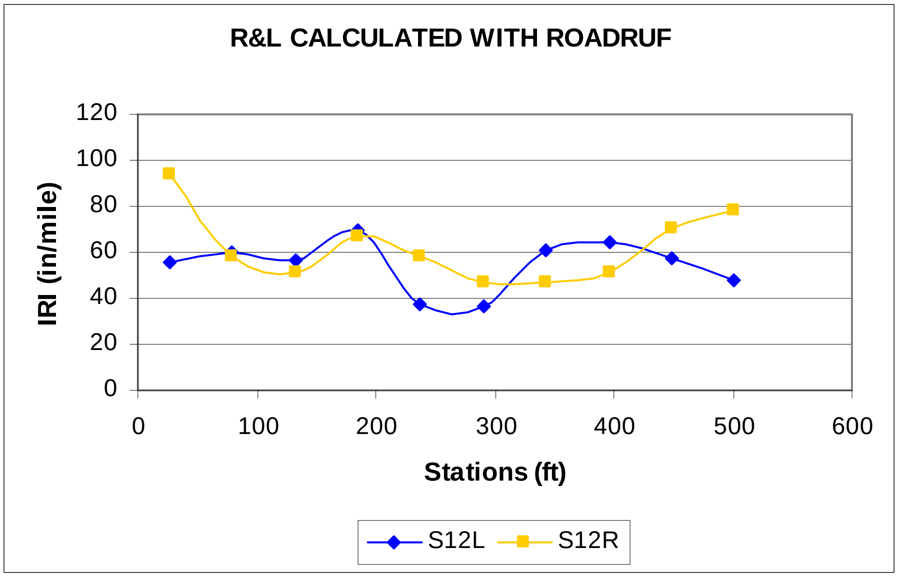


Figure B236: IRI, Route 55, Very Smooth, Section 12, Left and Right Wheel Path

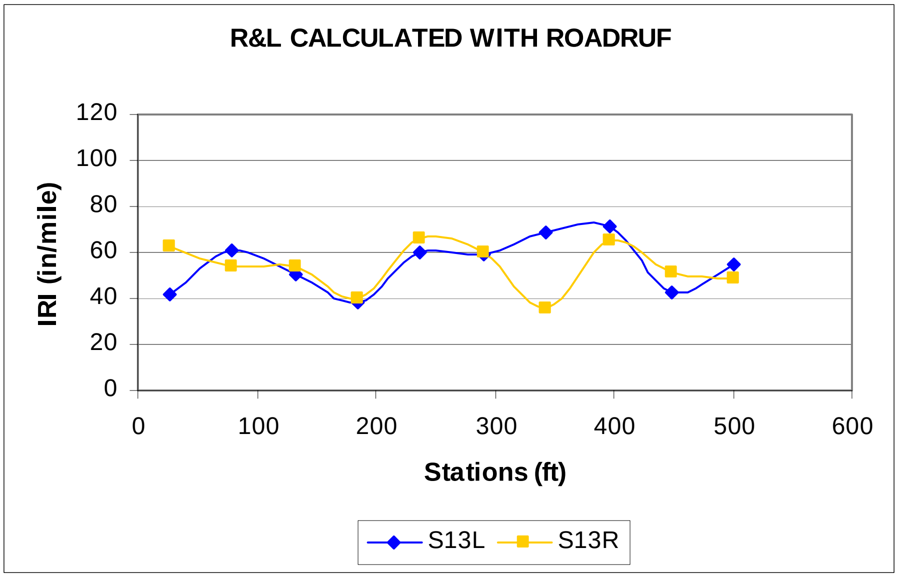


Figure B237: IRI, Route 55, Very Smooth, Section 13, Left and Right Wheel Path

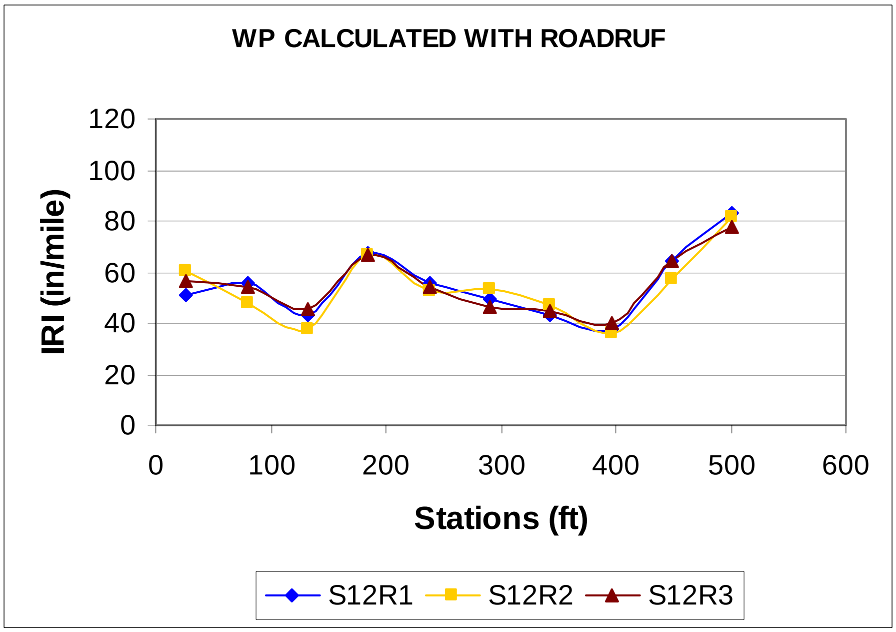


Figure B238: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

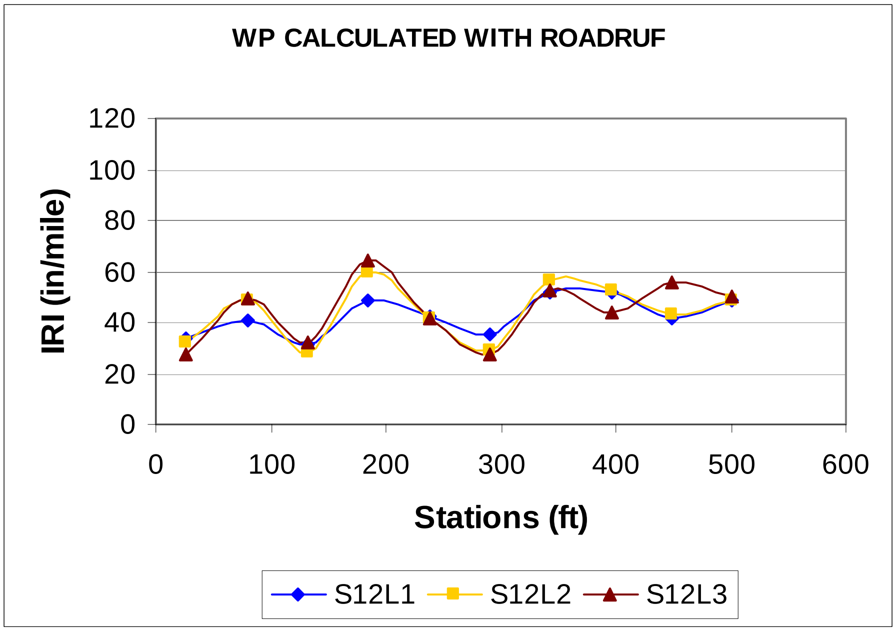


Figure B239: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

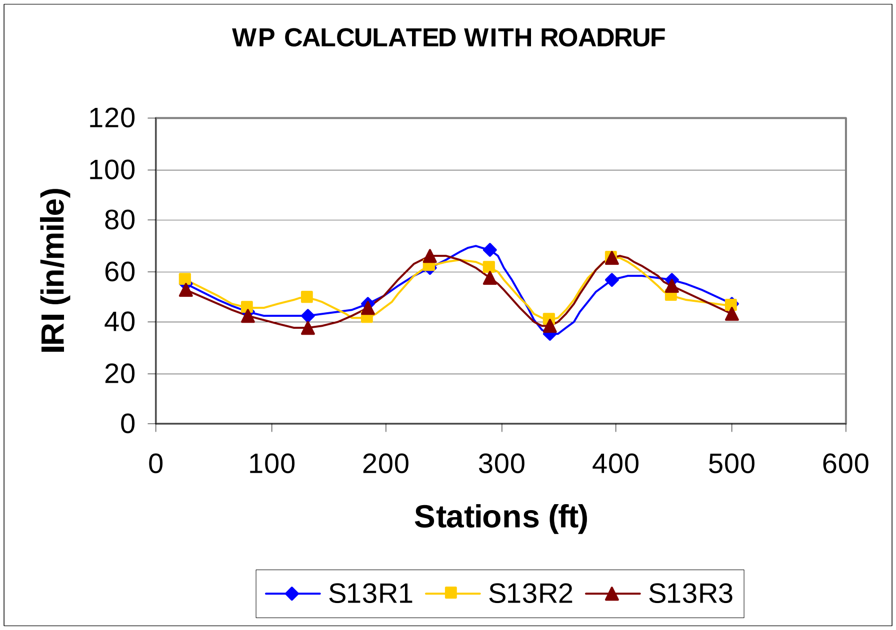


Figure B240: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

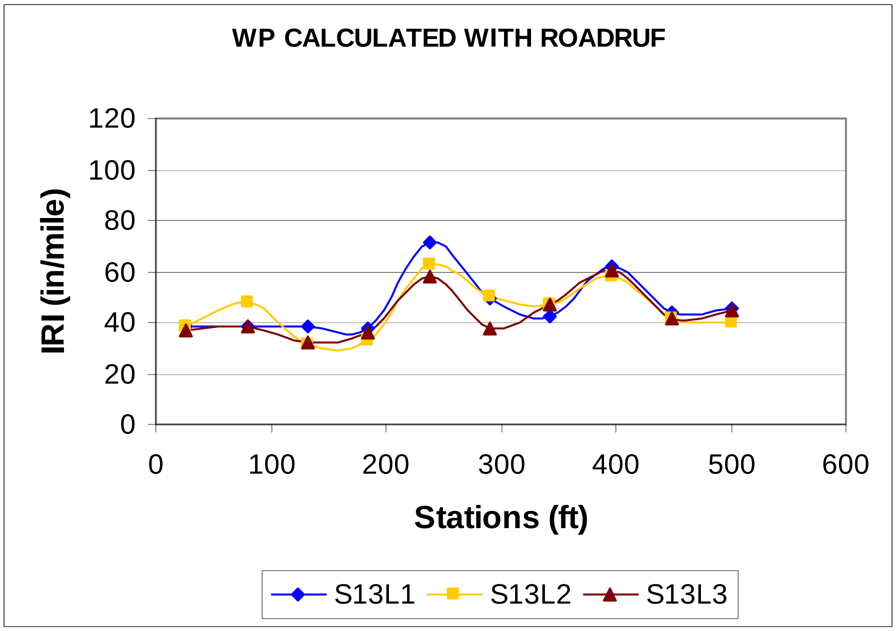


Figure B241: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

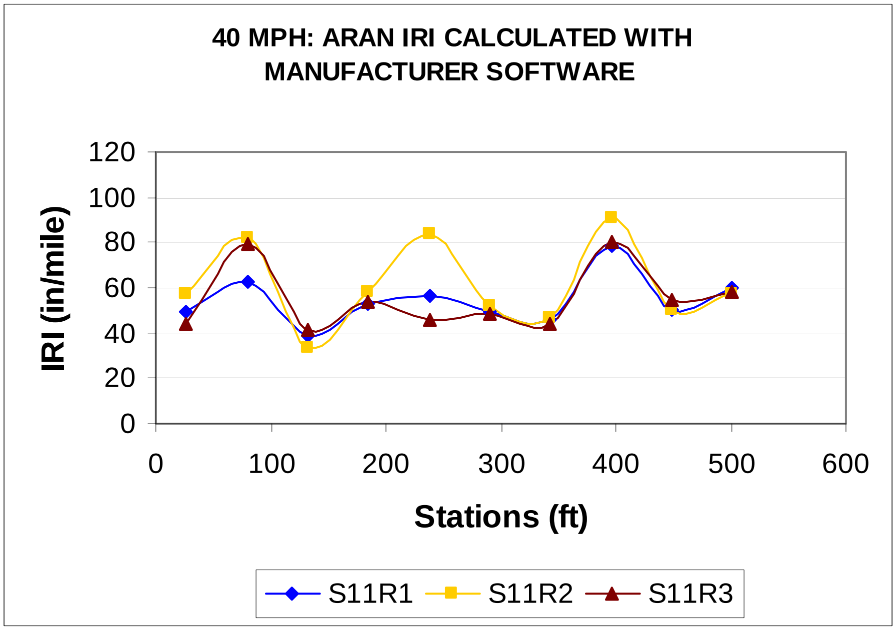


Figure B242: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

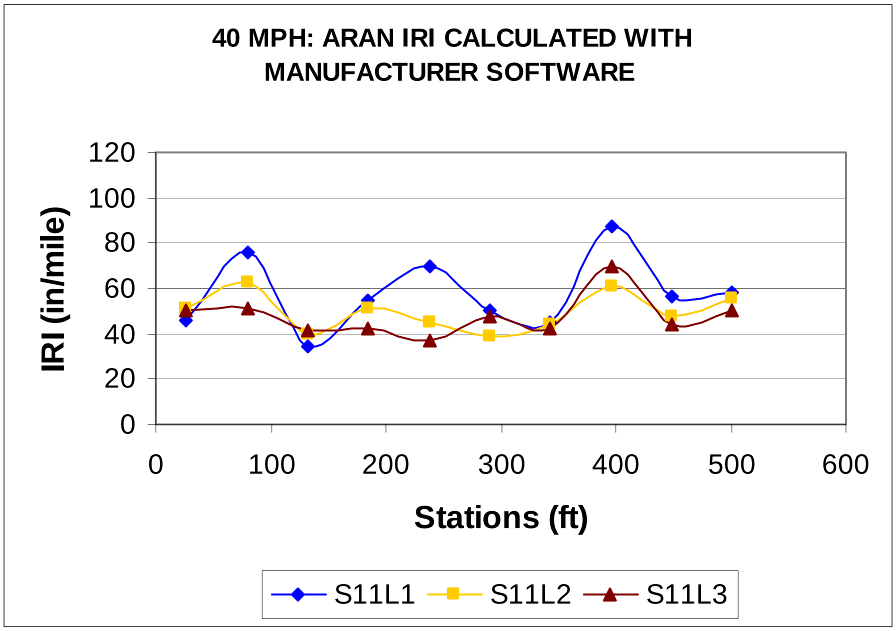


Figure B243: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

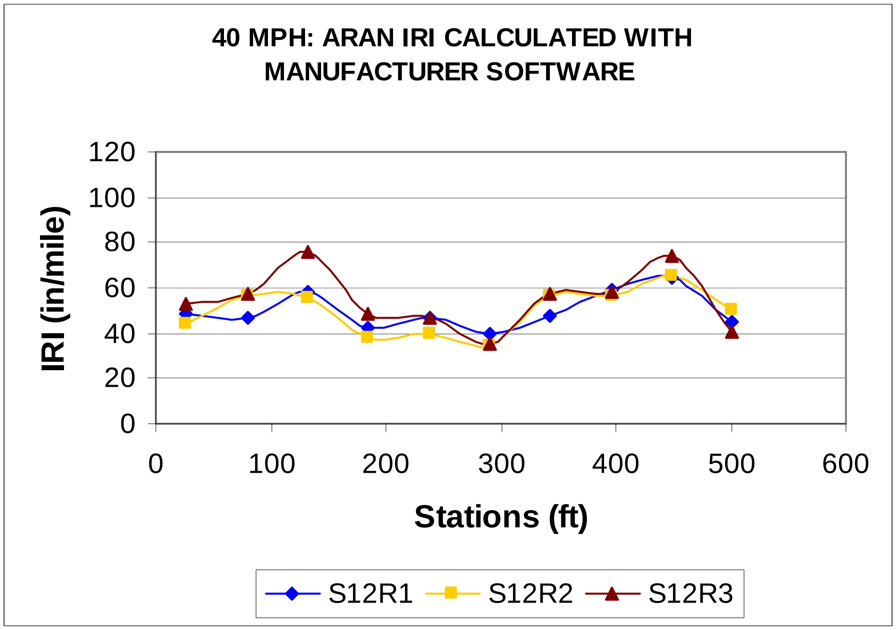


Figure B244: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

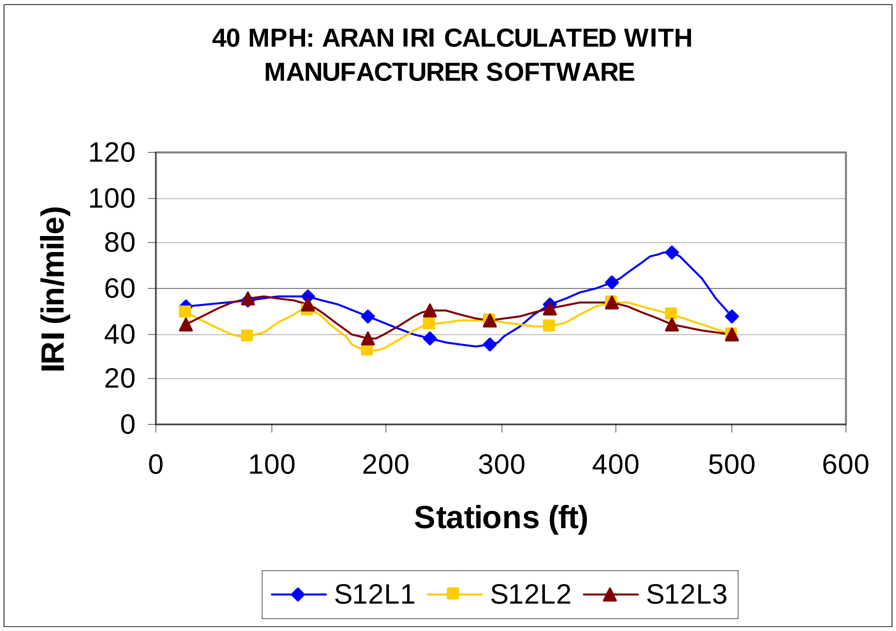


Figure B245: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

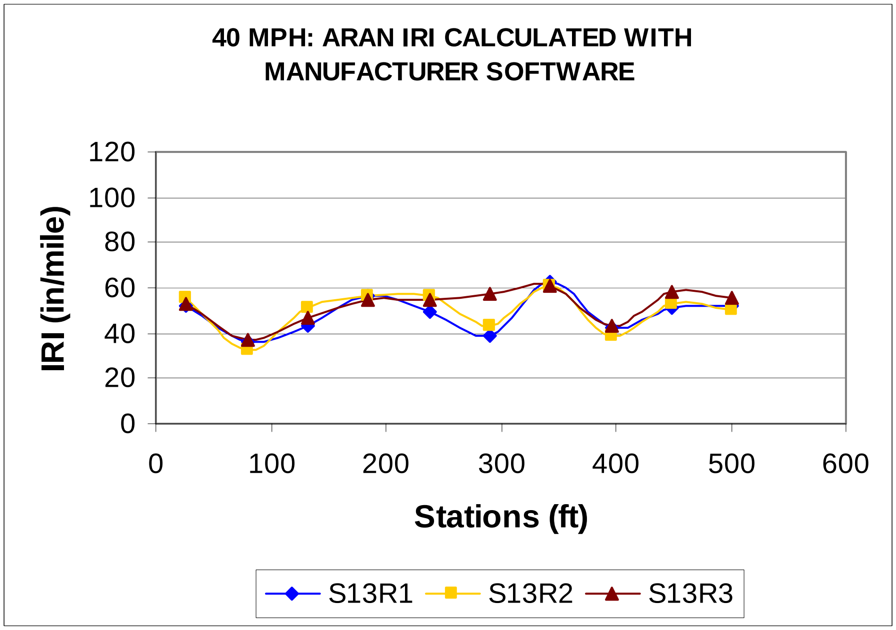


Figure B246: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

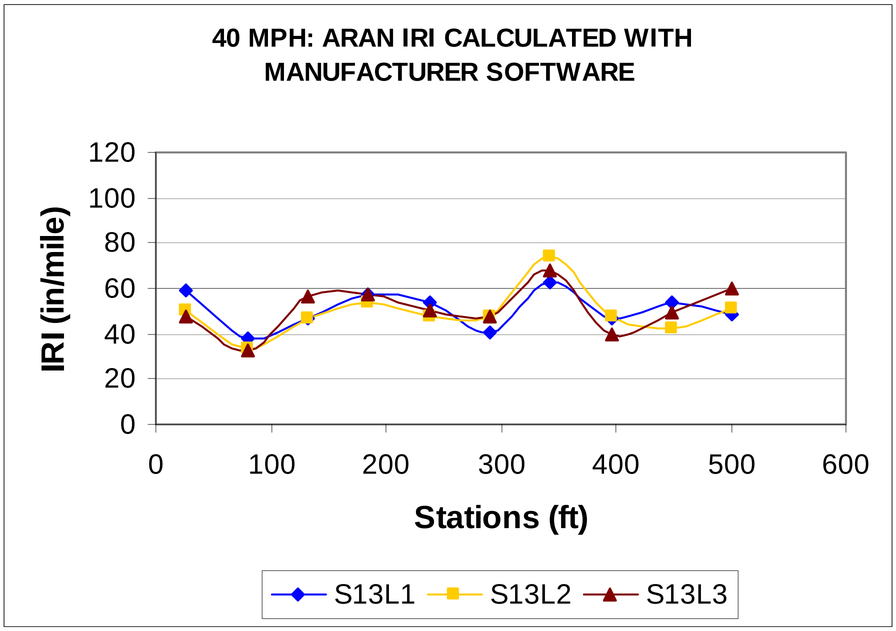


Figure B247: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

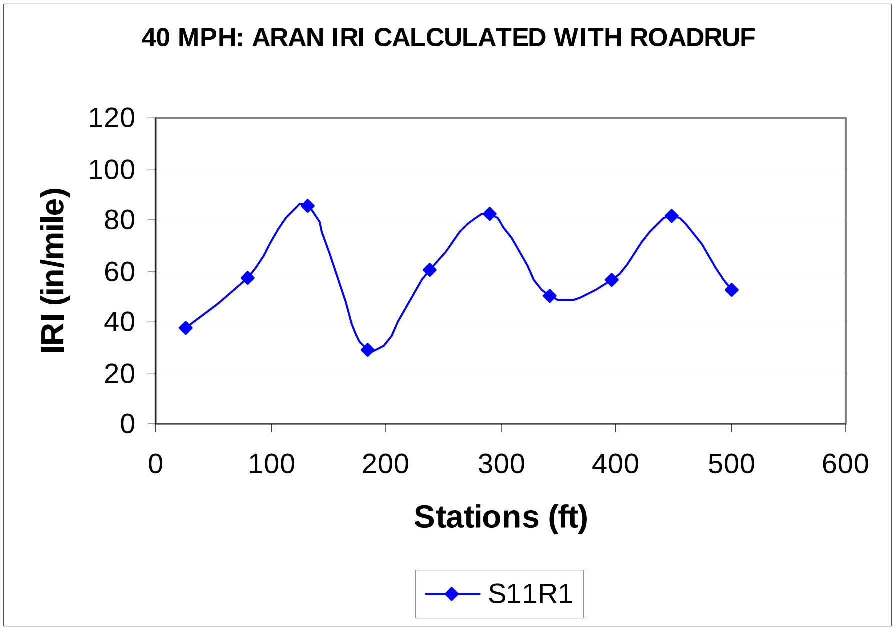


Figure B248: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

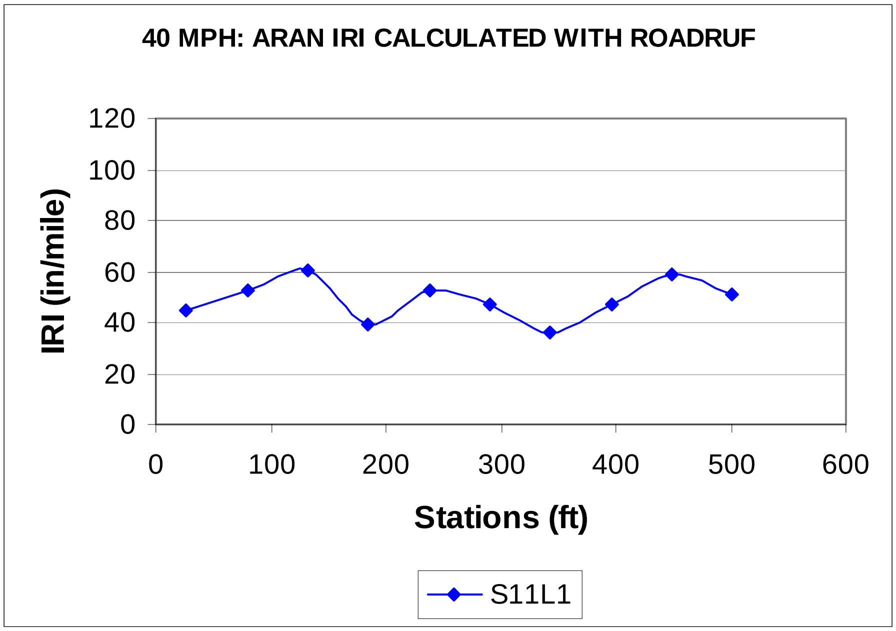


Figure B249: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

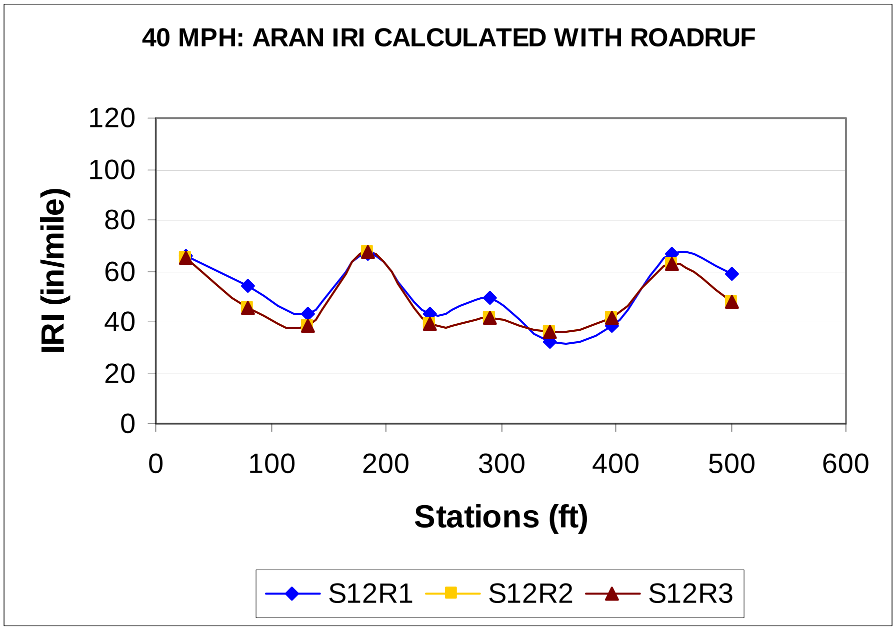


Figure B250: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

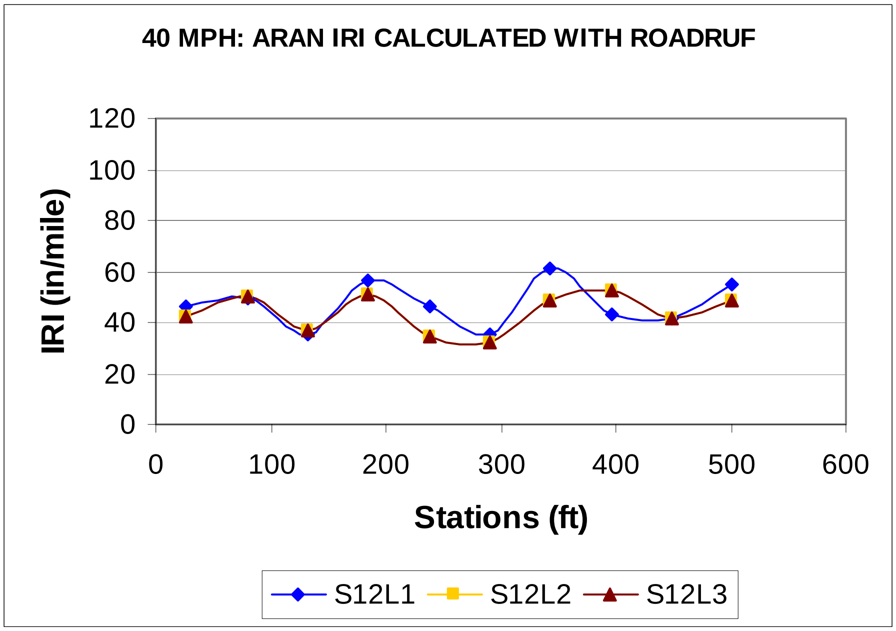


Figure B251: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

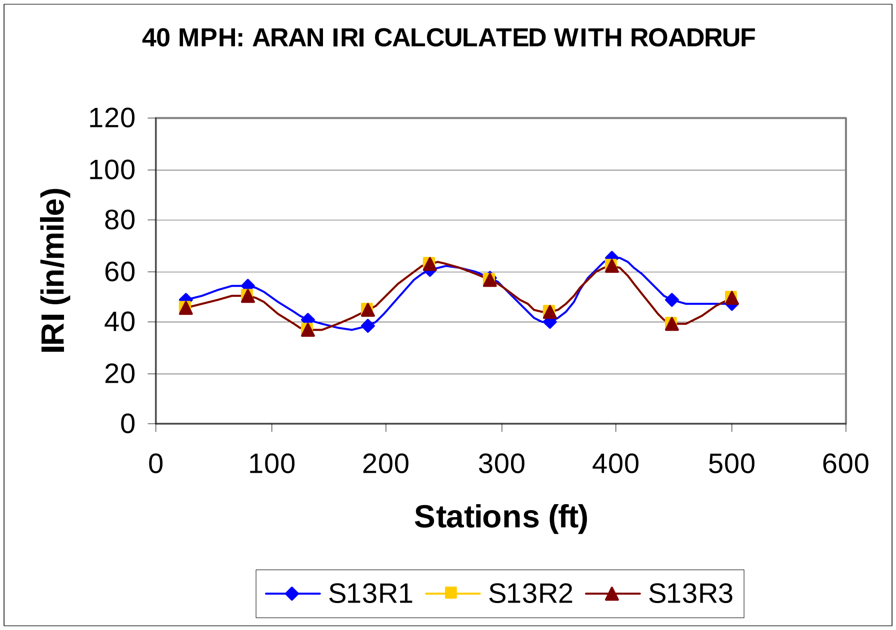


Figure B252: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

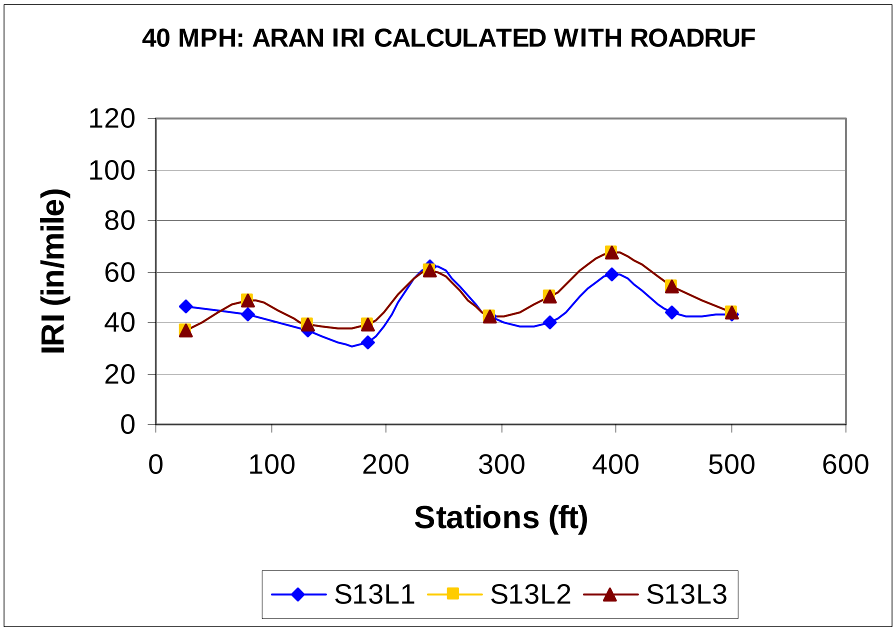


Figure B253: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

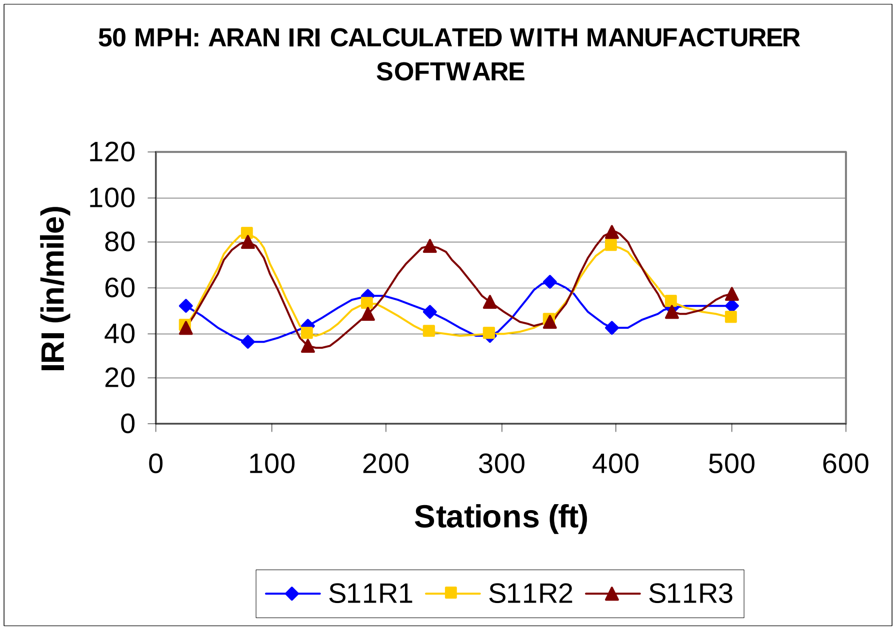


Figure B254: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

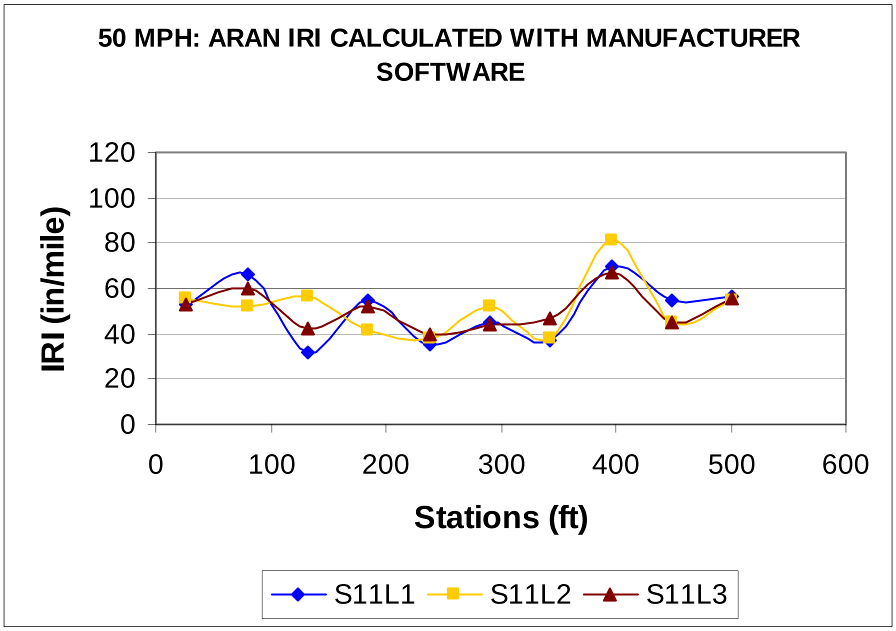


Figure B255: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

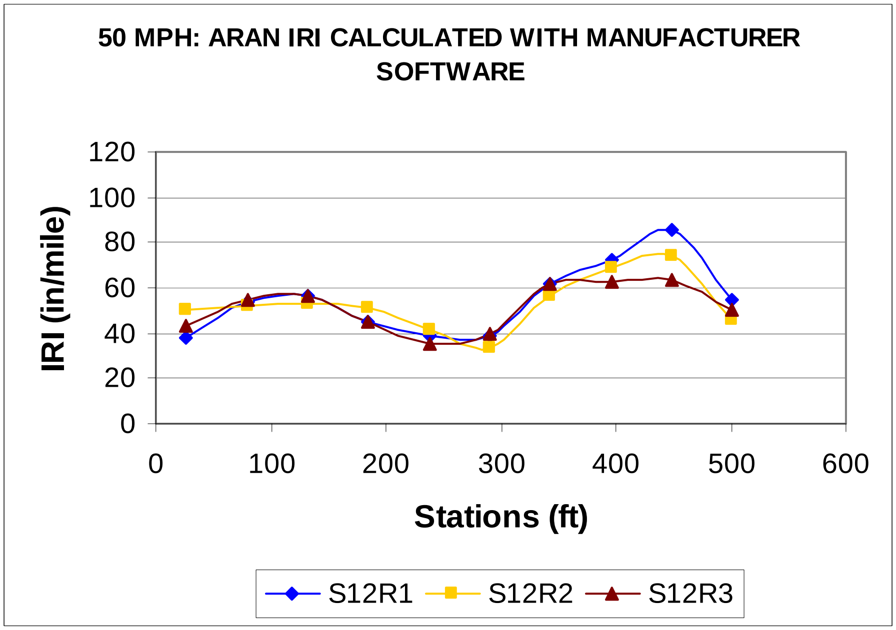


Figure B256: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

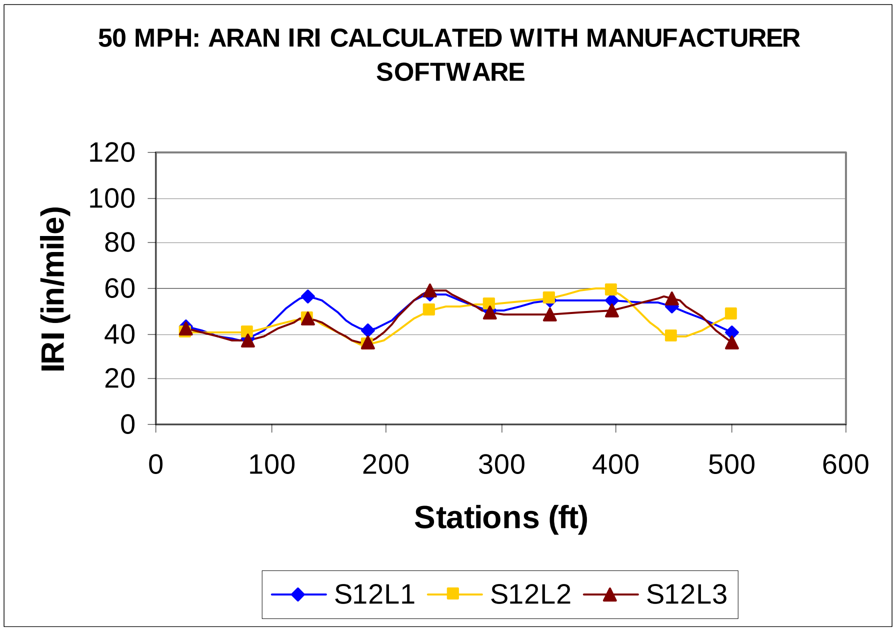


Figure B257: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

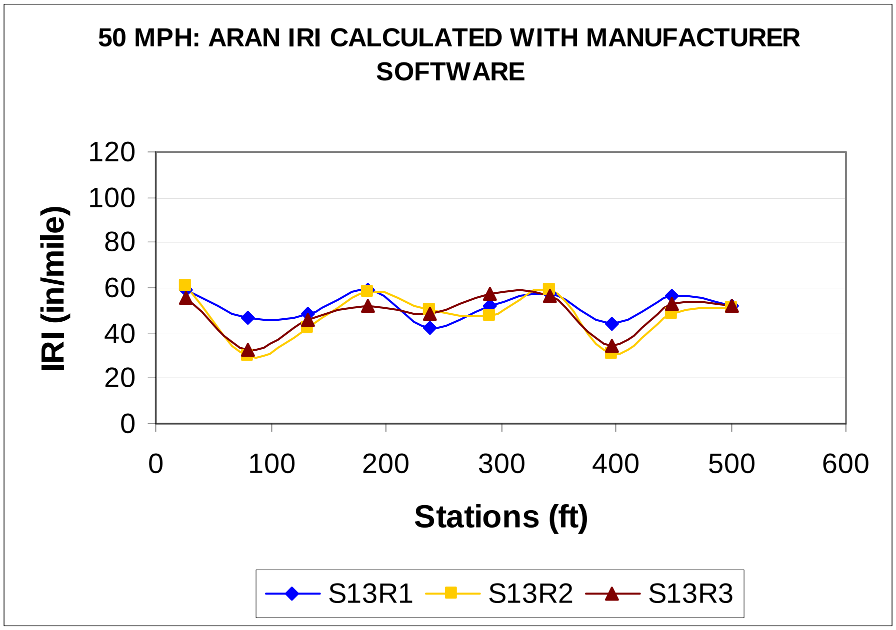


Figure B258: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

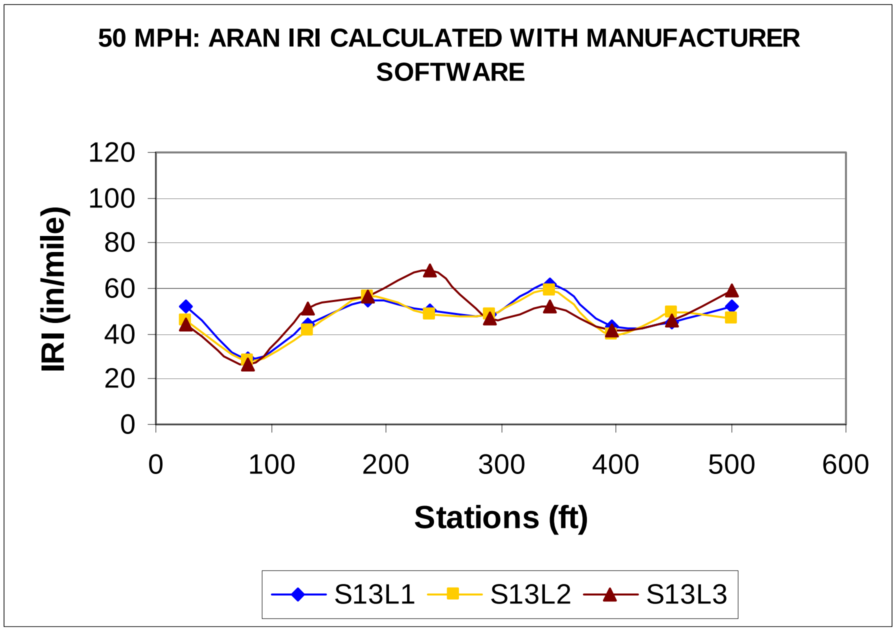


Figure B259: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

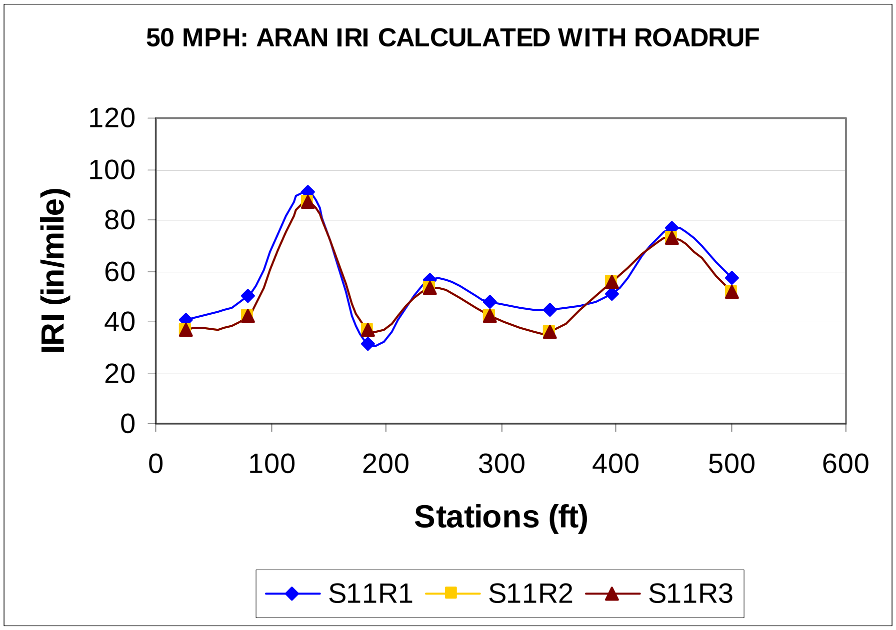


Figure B260: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

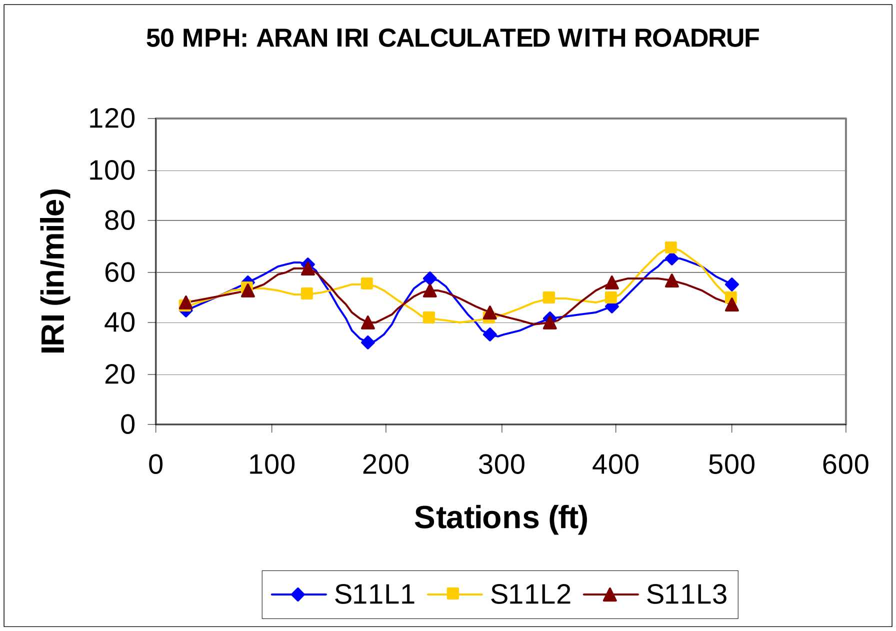


Figure B261: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

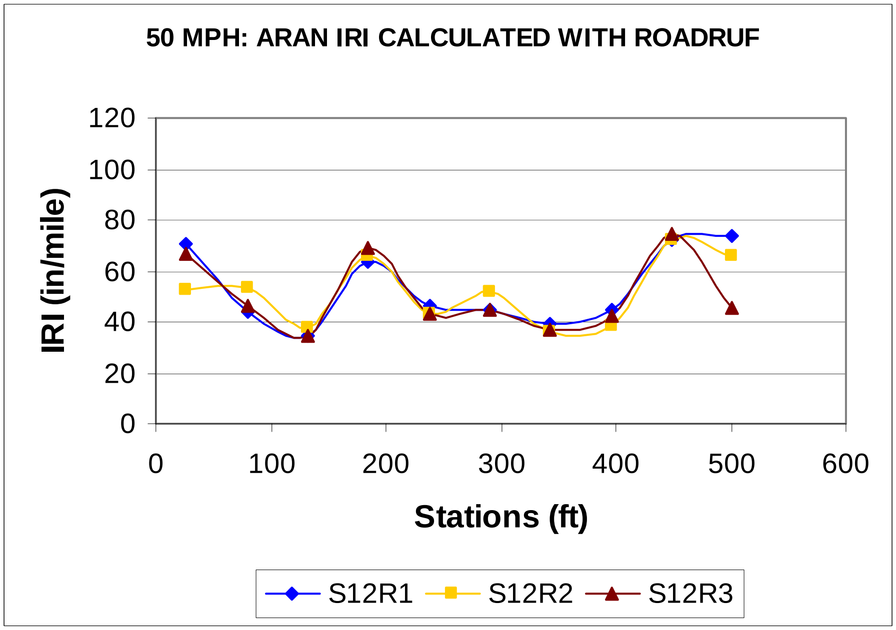


Figure B262: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

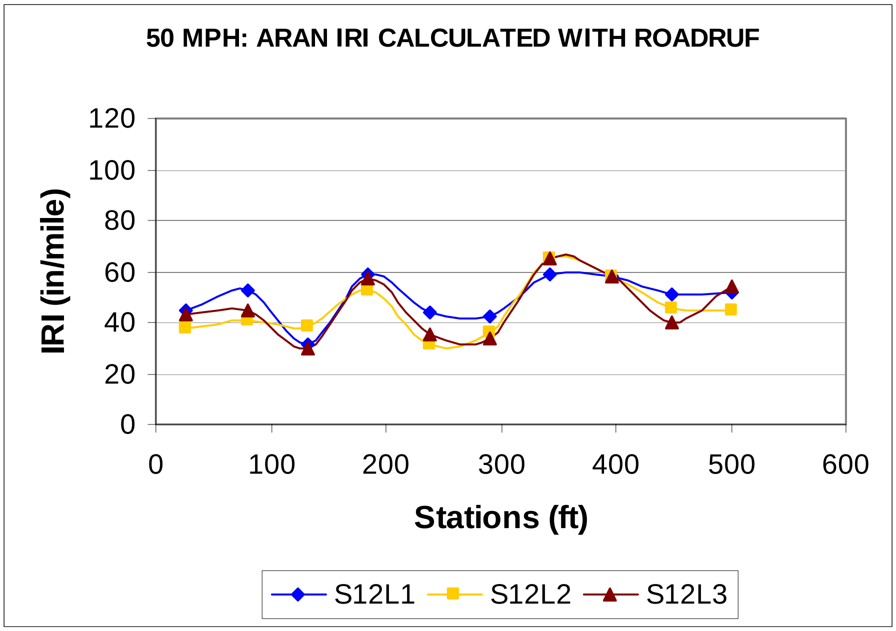


Figure B263: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

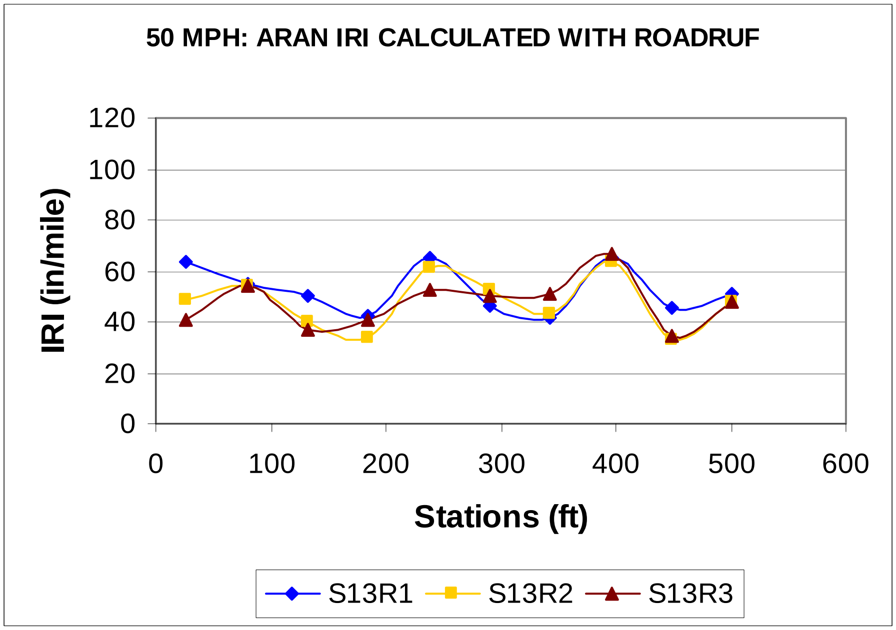


Figure B264: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

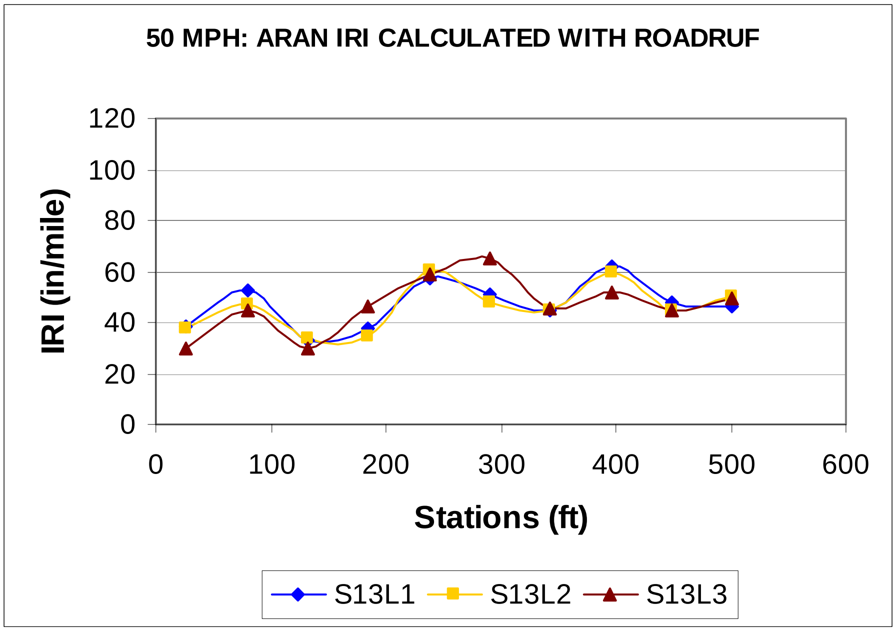


Figure B265: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

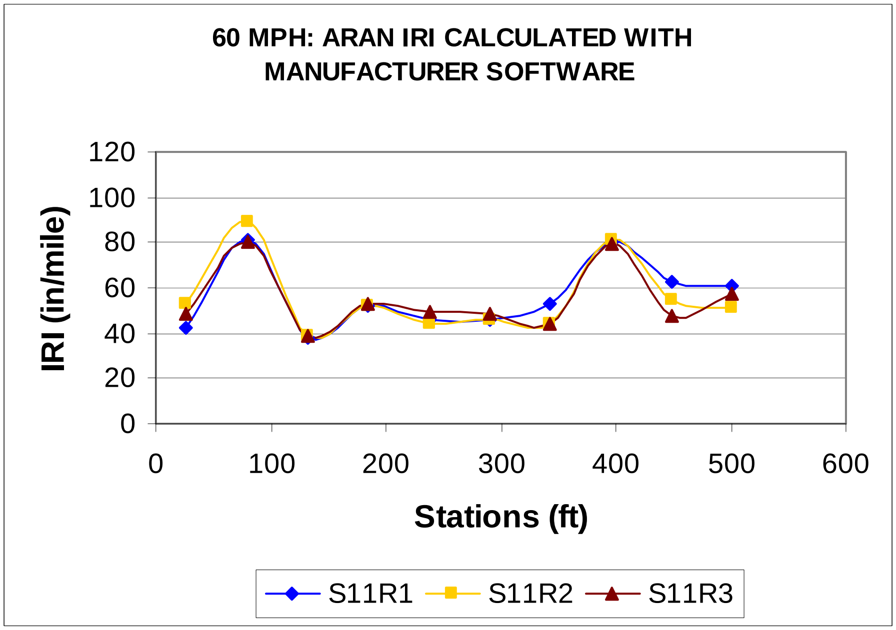


Figure B266: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

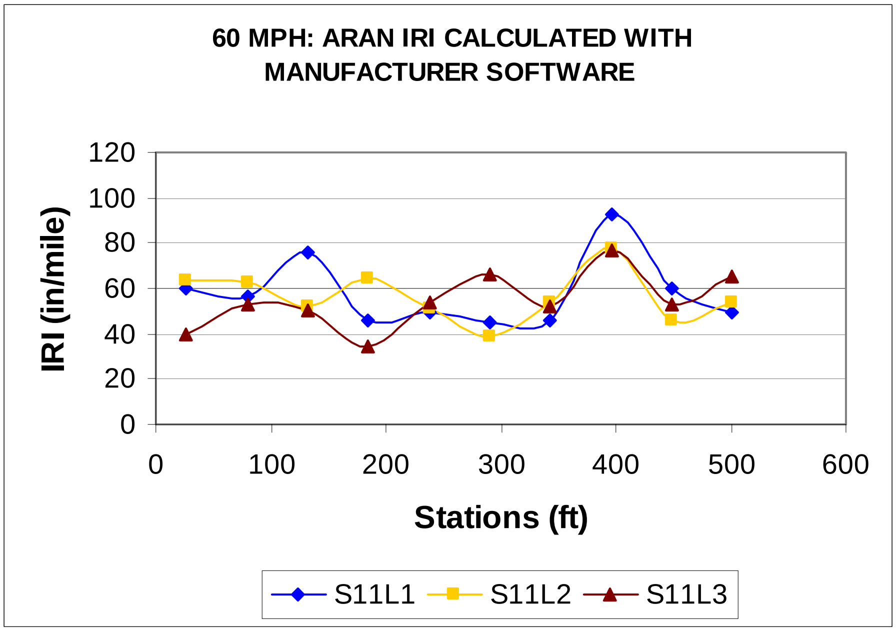


Figure B267: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

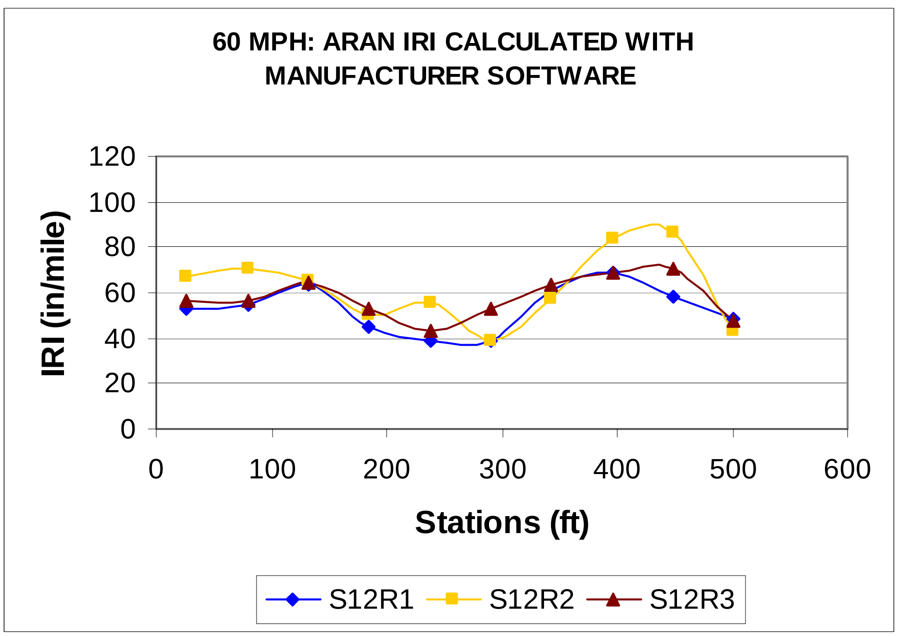


Figure B268: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

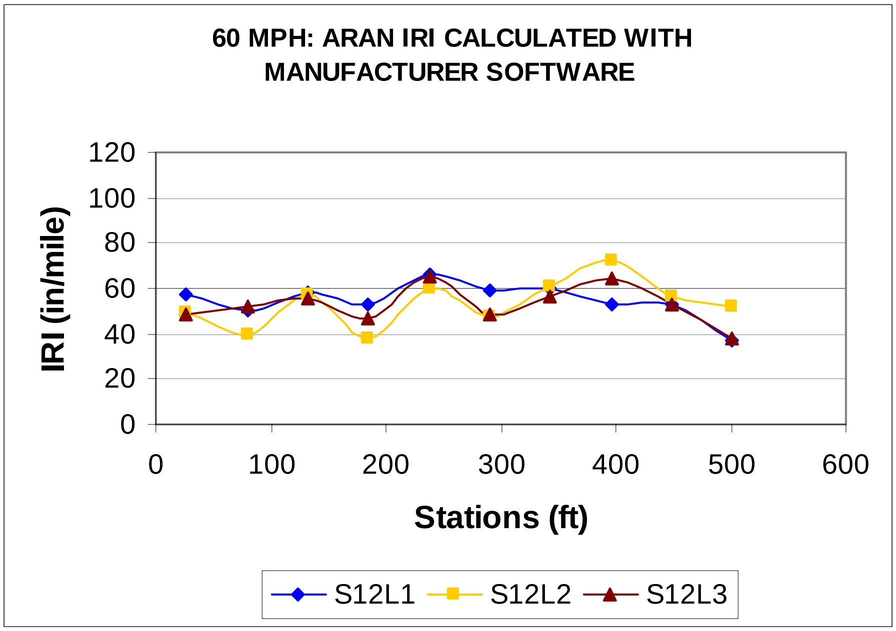


Figure B269: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

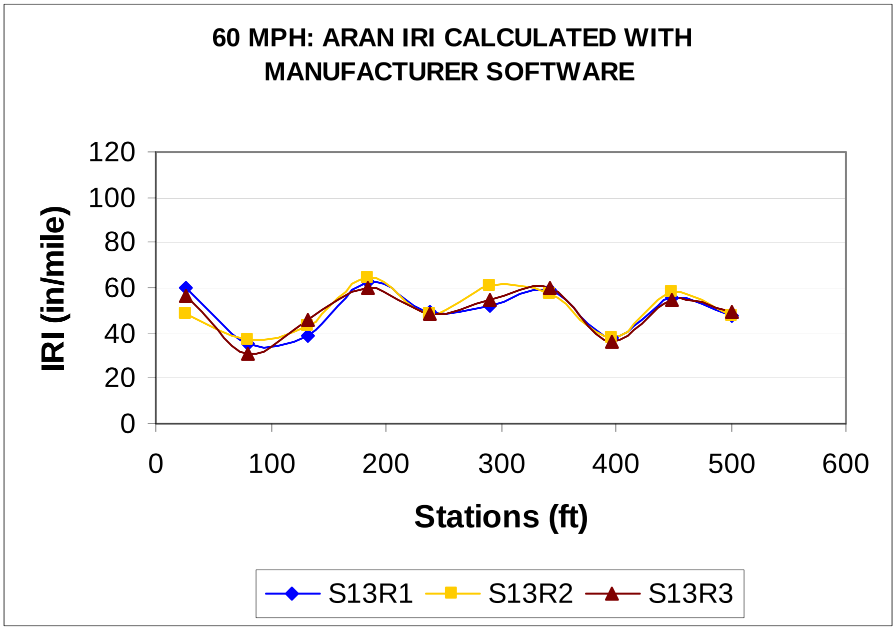


Figure B270: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

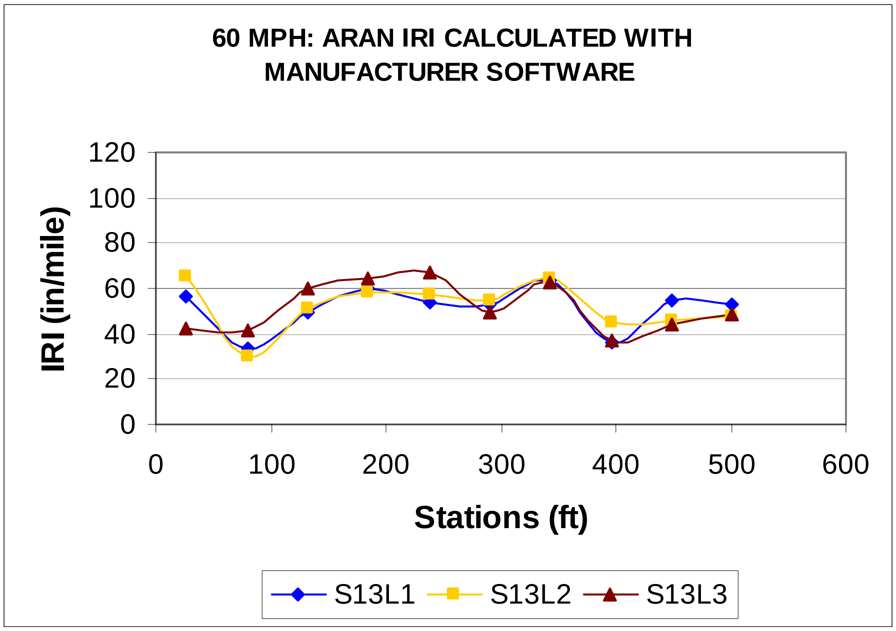


Figure B271: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

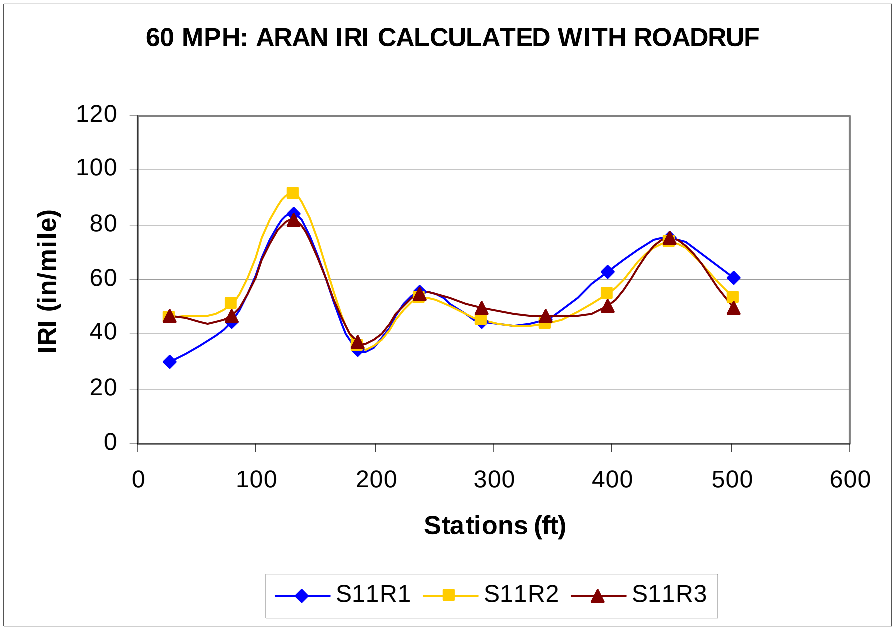


Figure B272: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

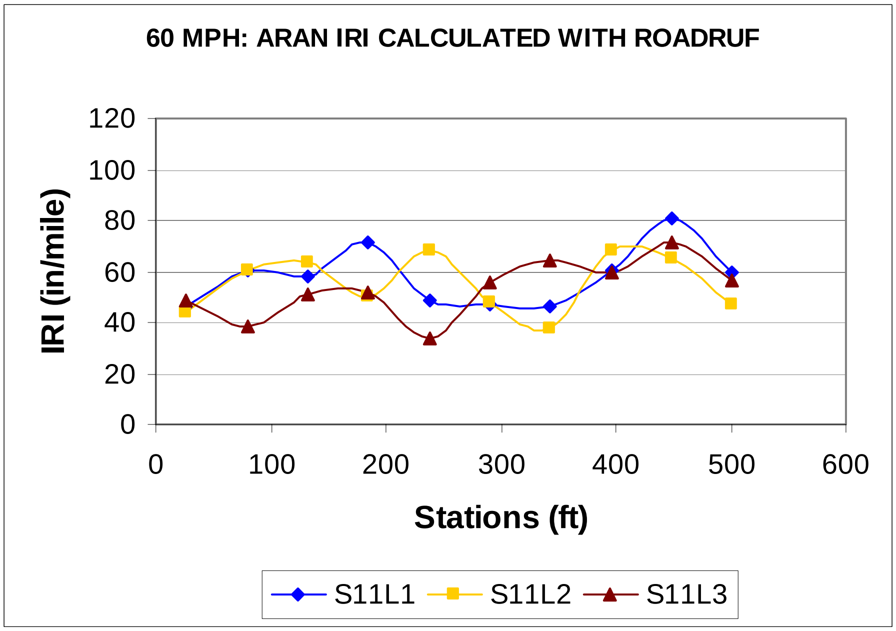


Figure B273: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

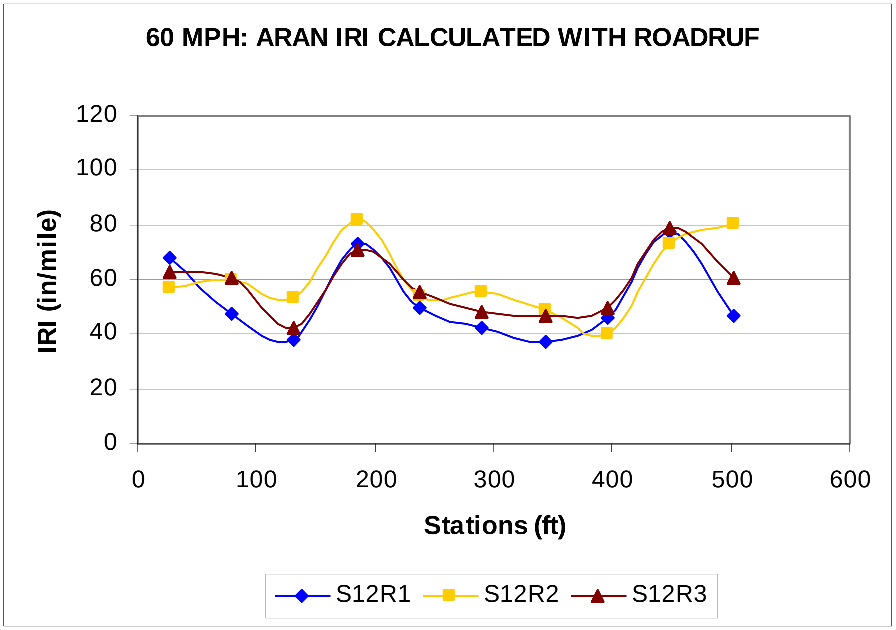


Figure B274: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

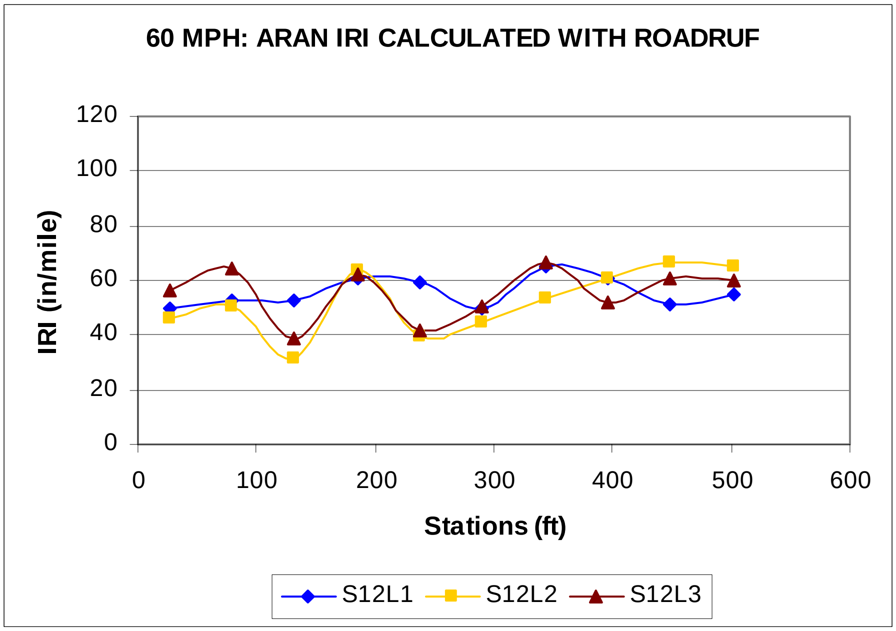


Figure B275: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

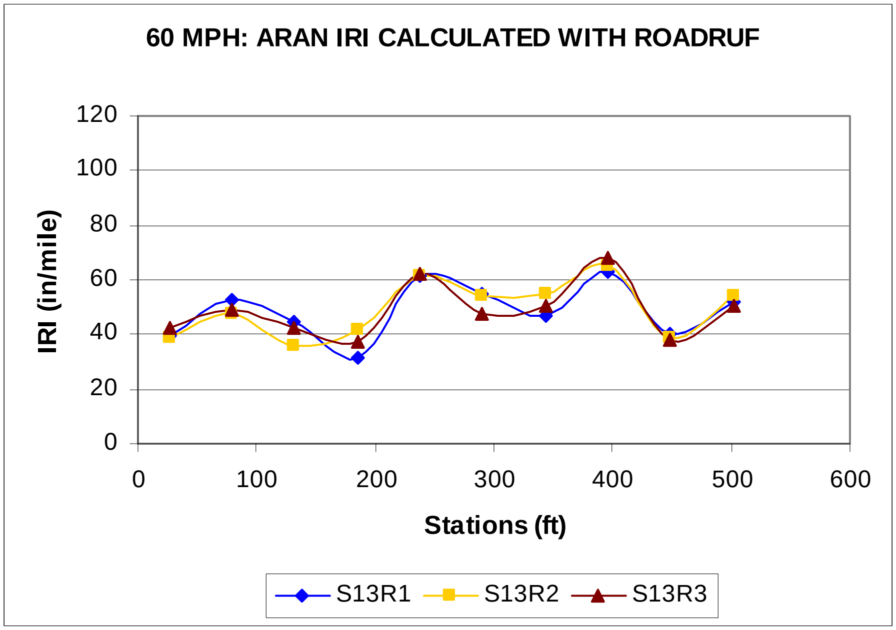


Figure B276: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

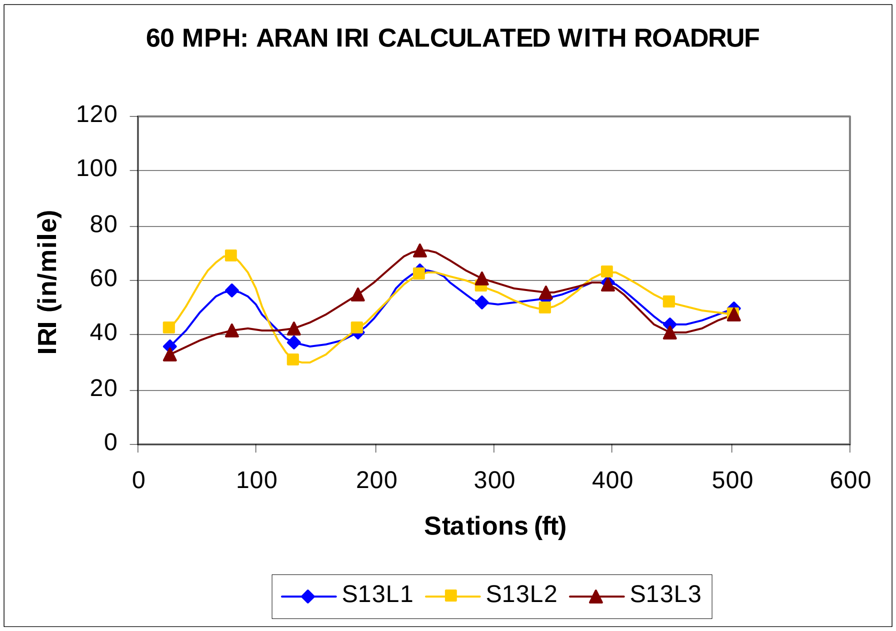


Figure B277: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

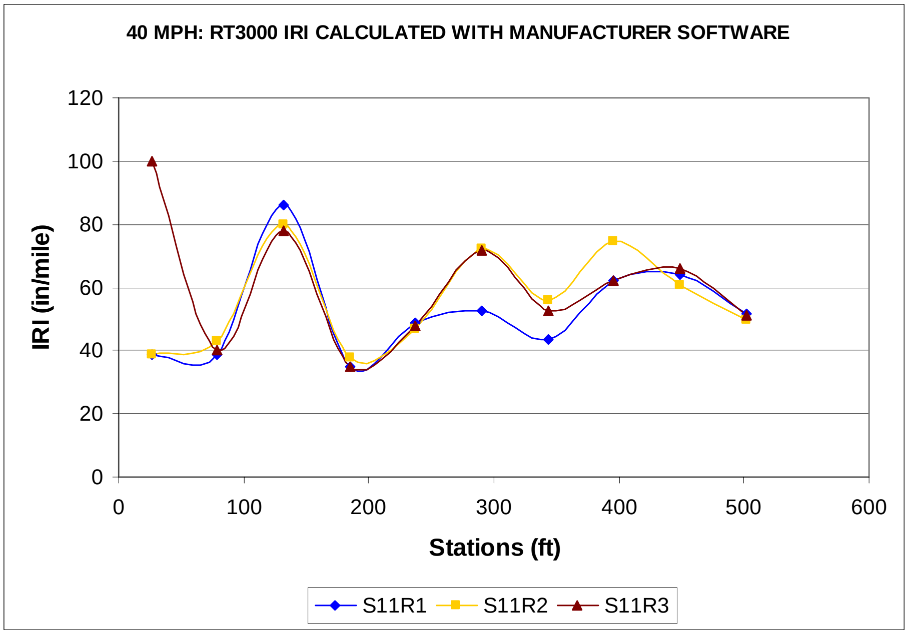


Figure B278: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

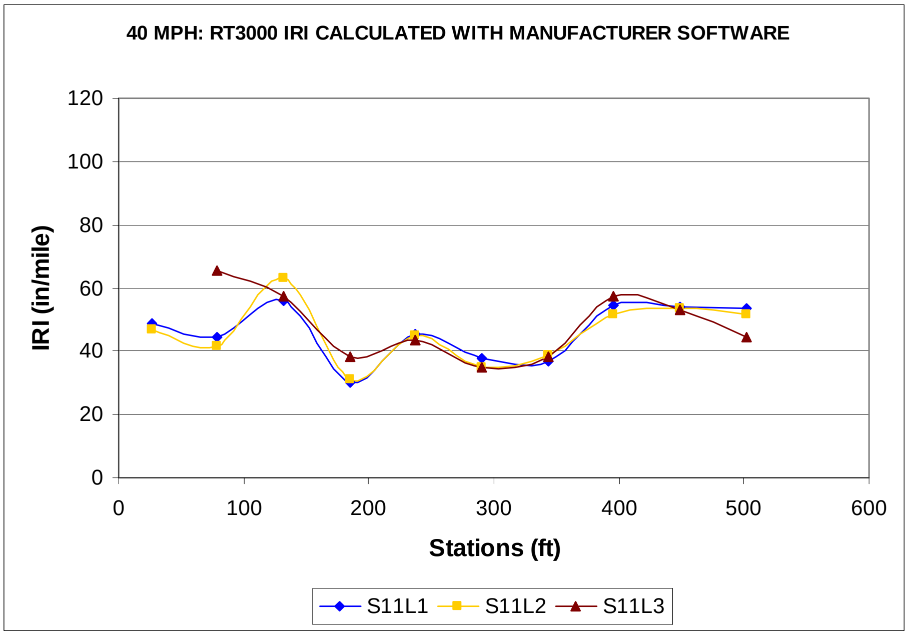


Figure B279: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

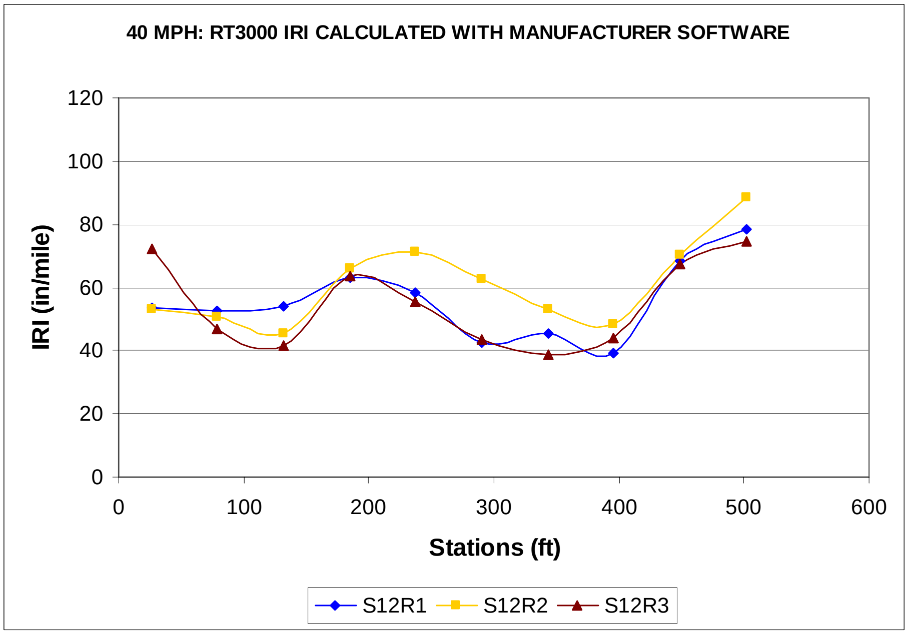


Figure B280: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

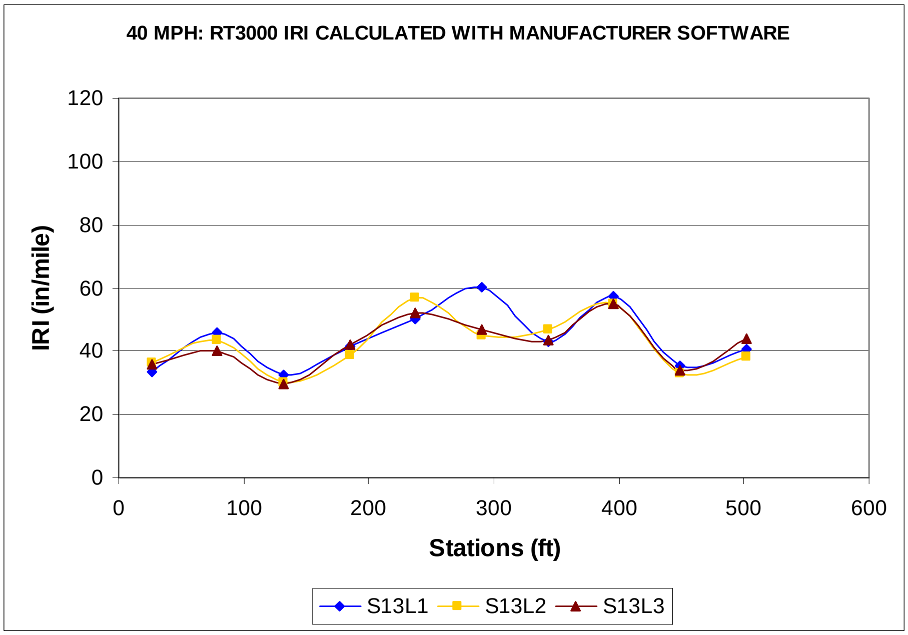


Figure B281: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

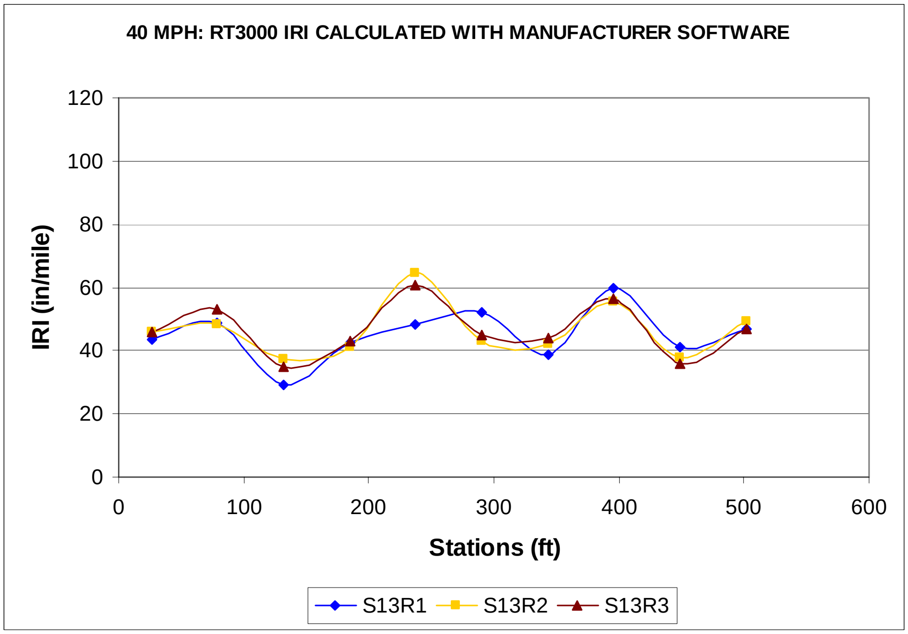


Figure B282: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

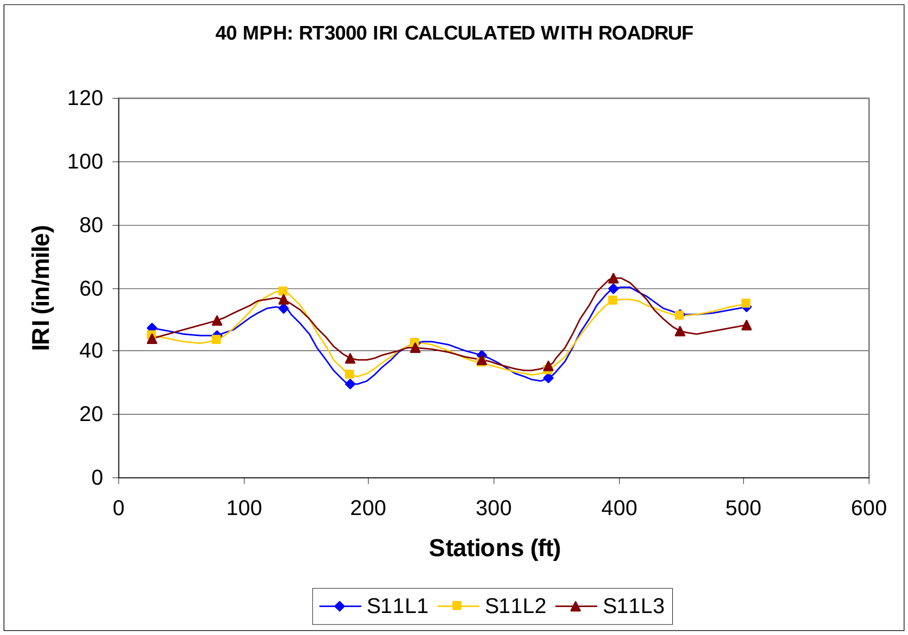


Figure B283: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

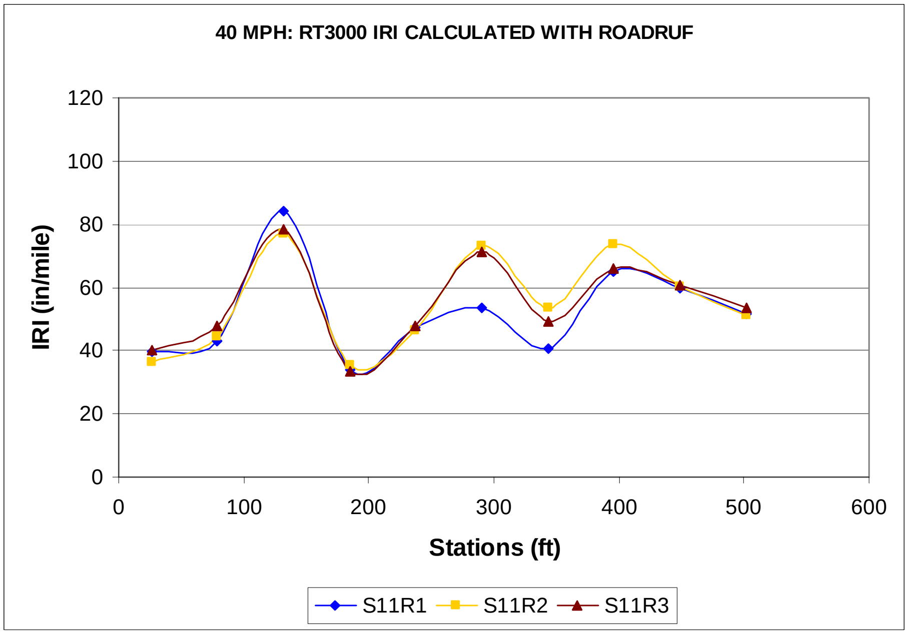


Figure B284: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

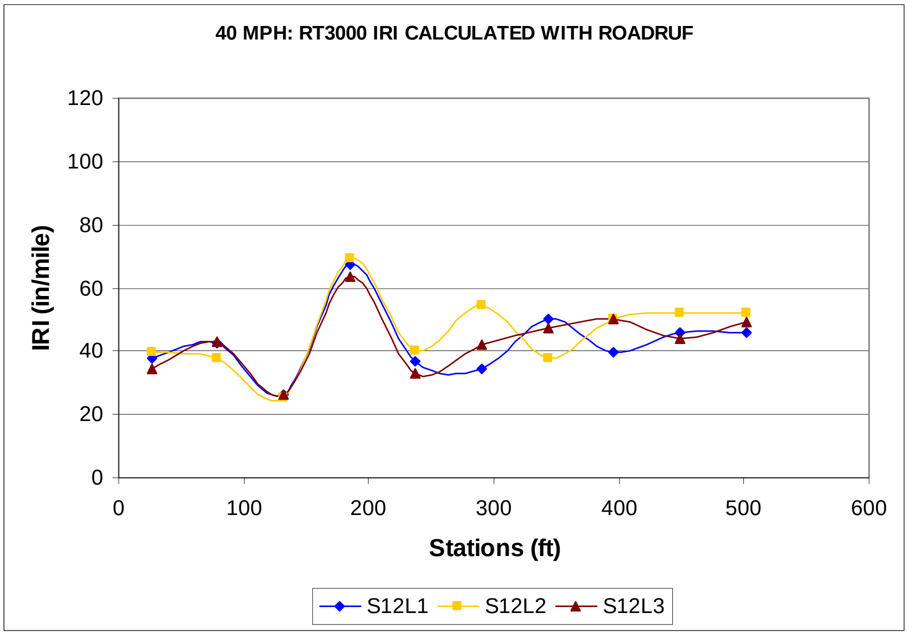


Figure B285: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

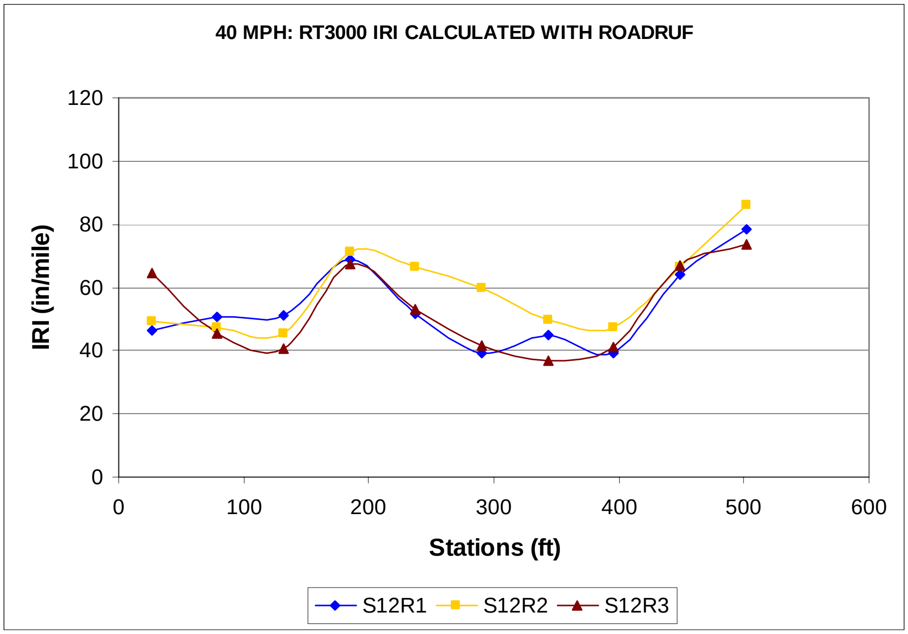


Figure B286: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

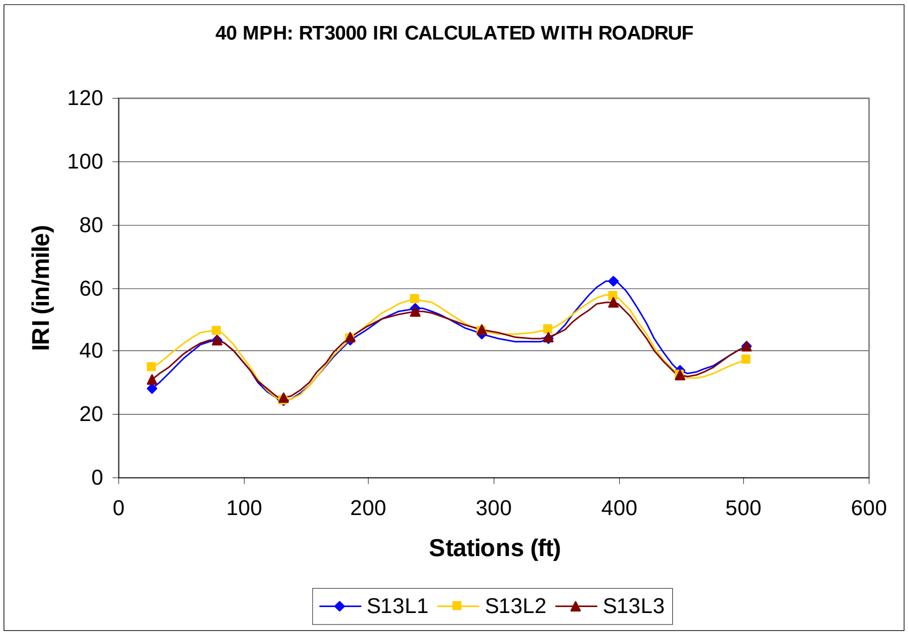


Figure B287: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

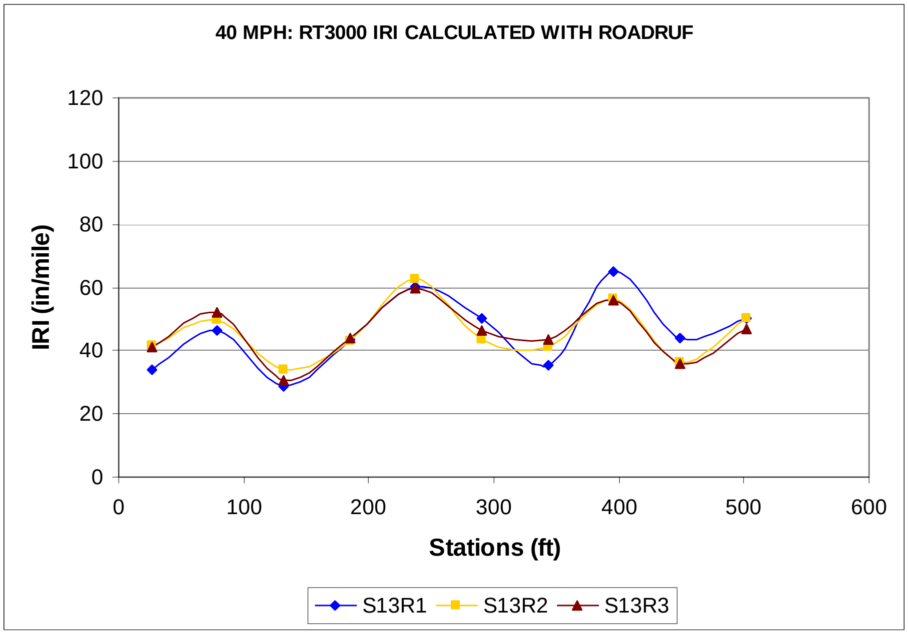


Figure B288: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

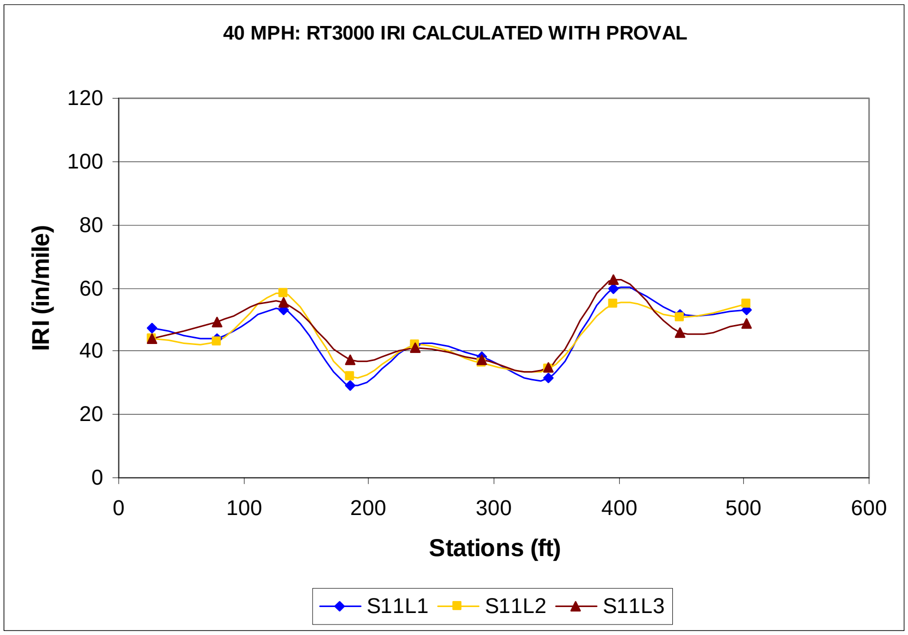


Figure B289: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

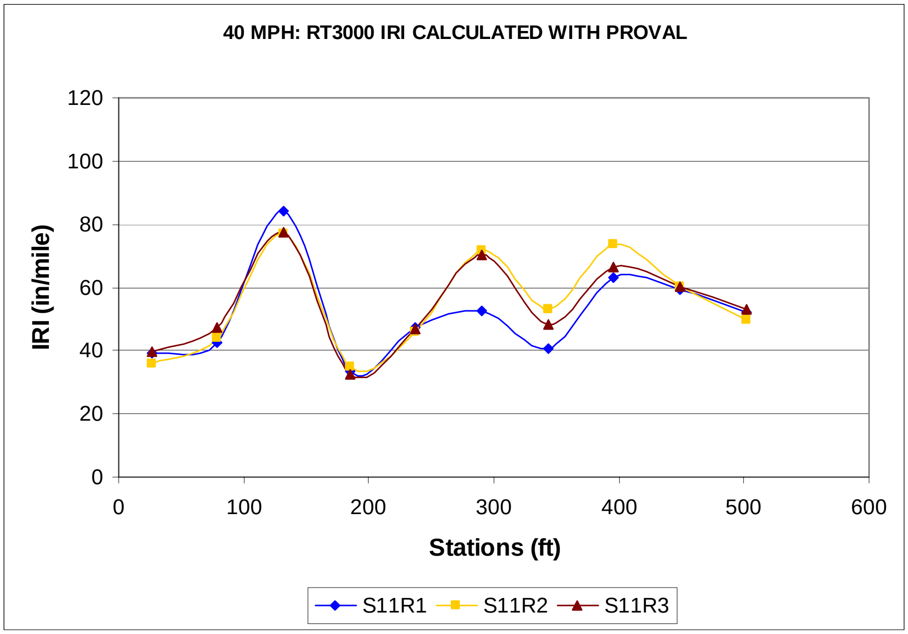


Figure B290: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

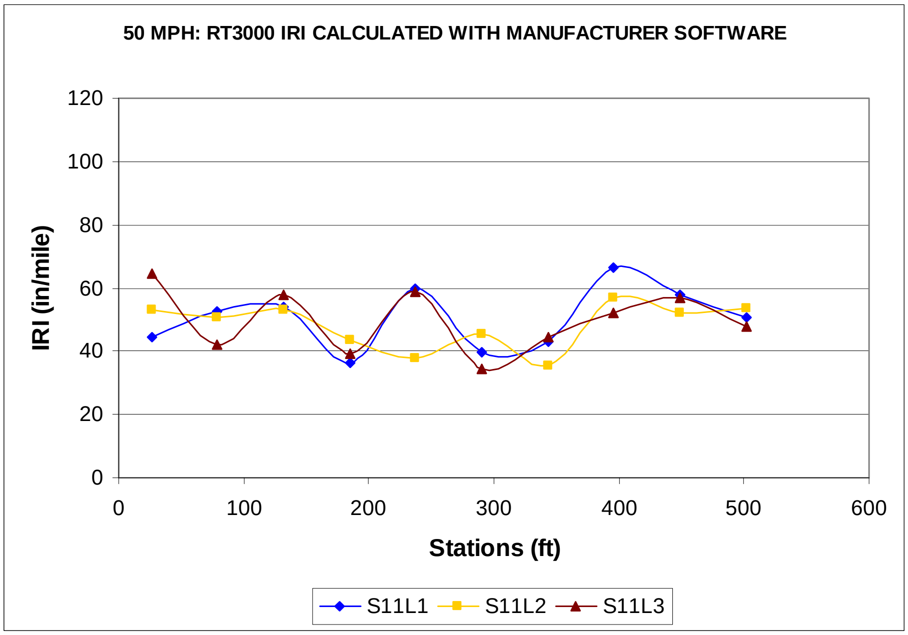


Figure B291: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

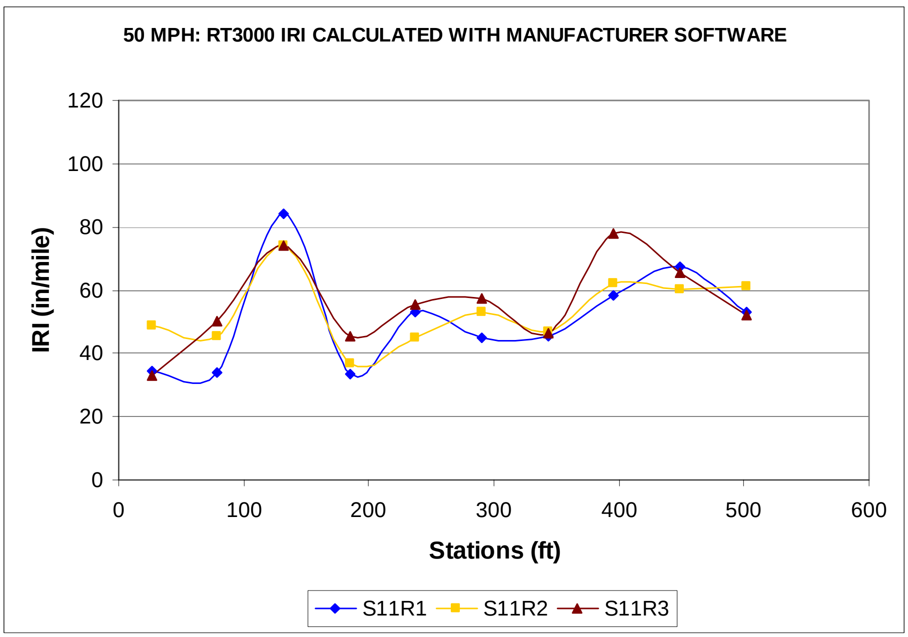


Figure B292: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

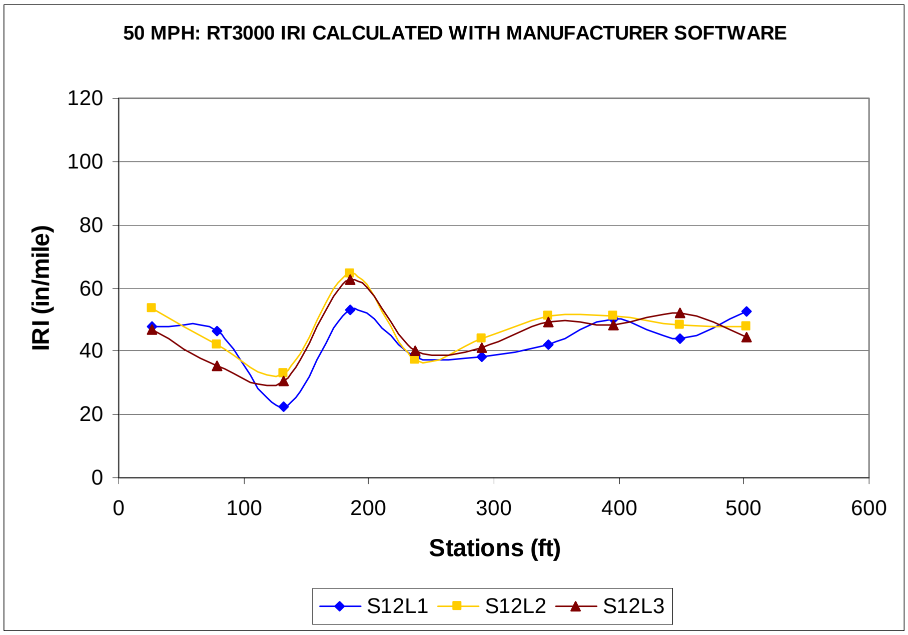


Figure B293: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

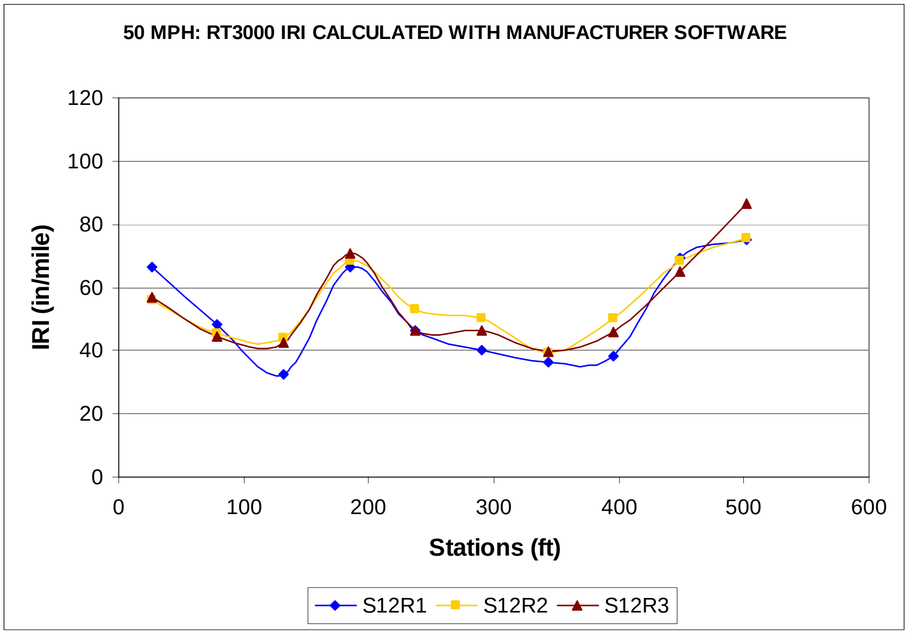


Figure B294: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

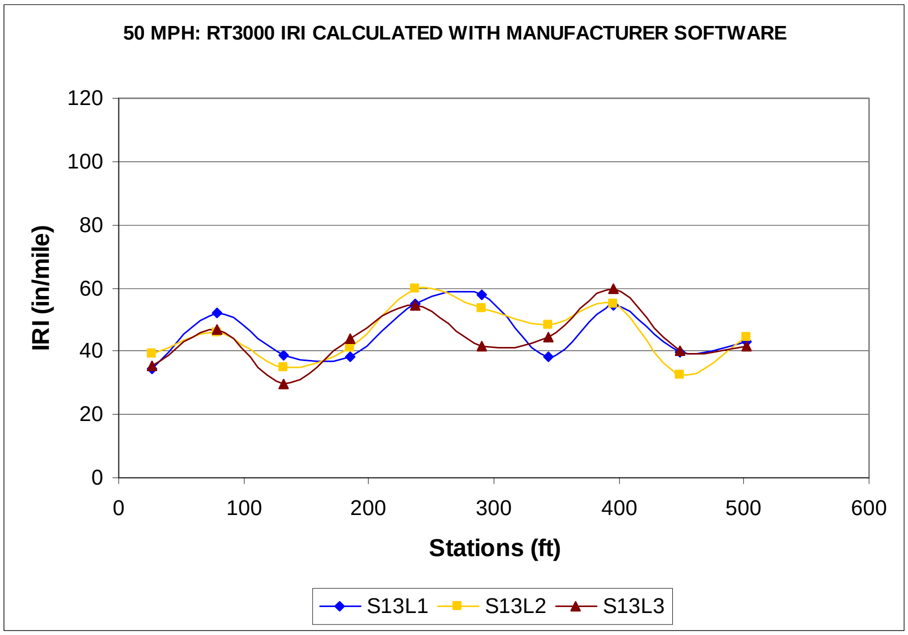


Figure B295: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

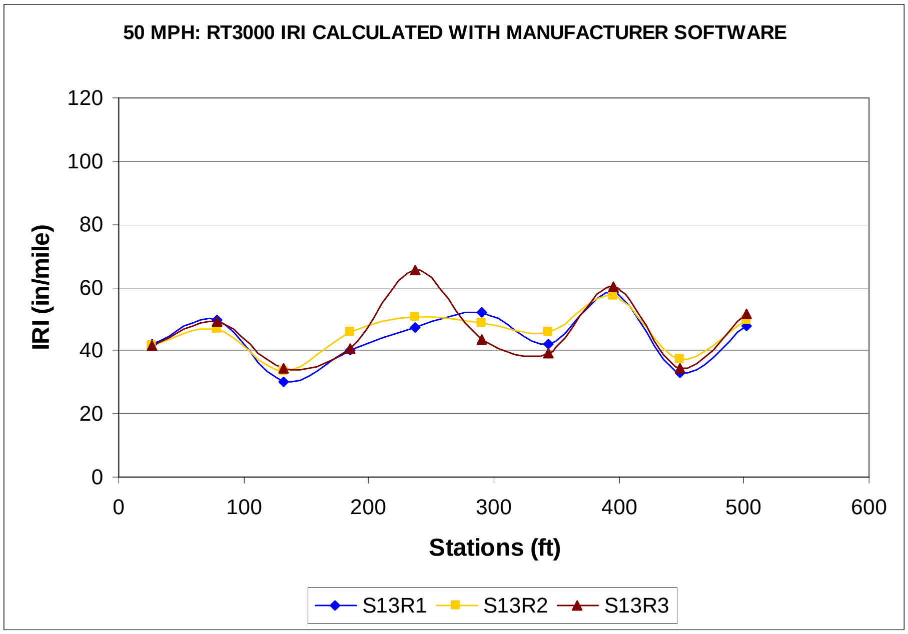


Figure B296: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

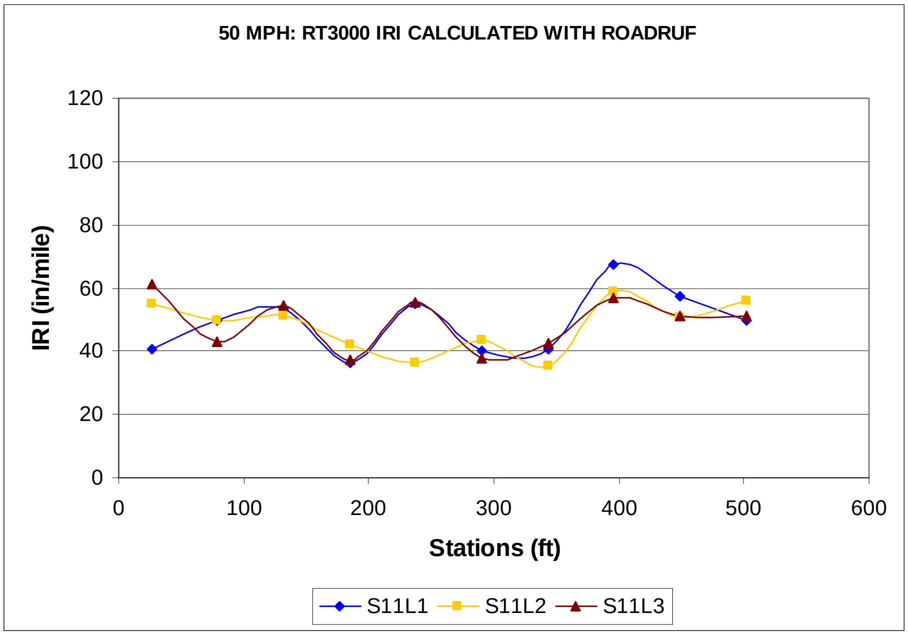


Figure B297: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

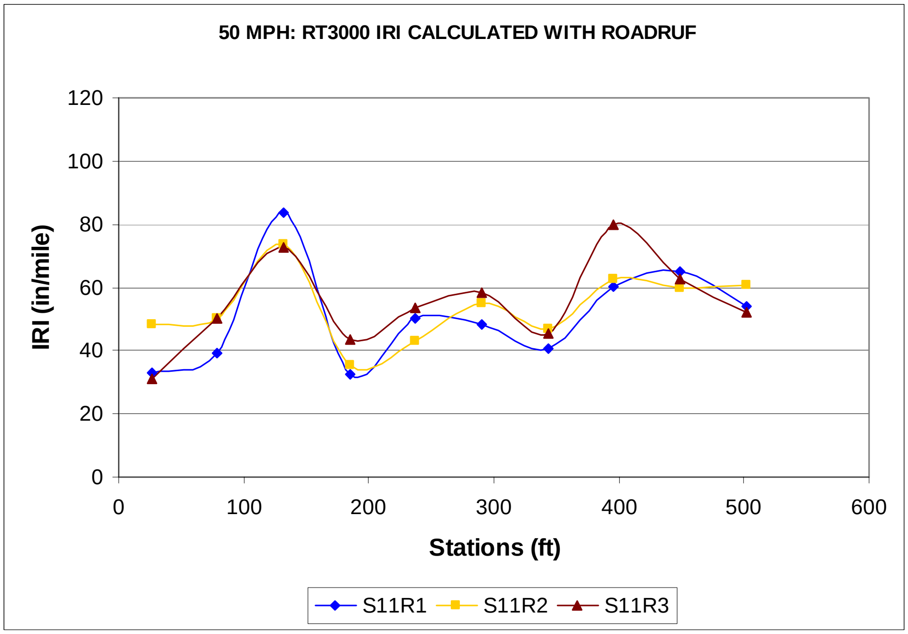


Figure B298: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

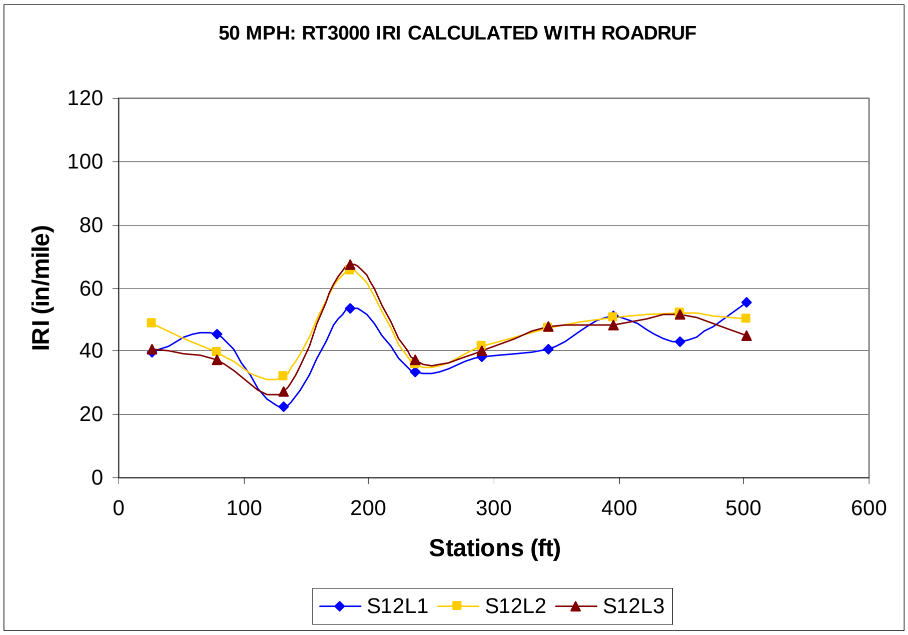


Figure B299: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

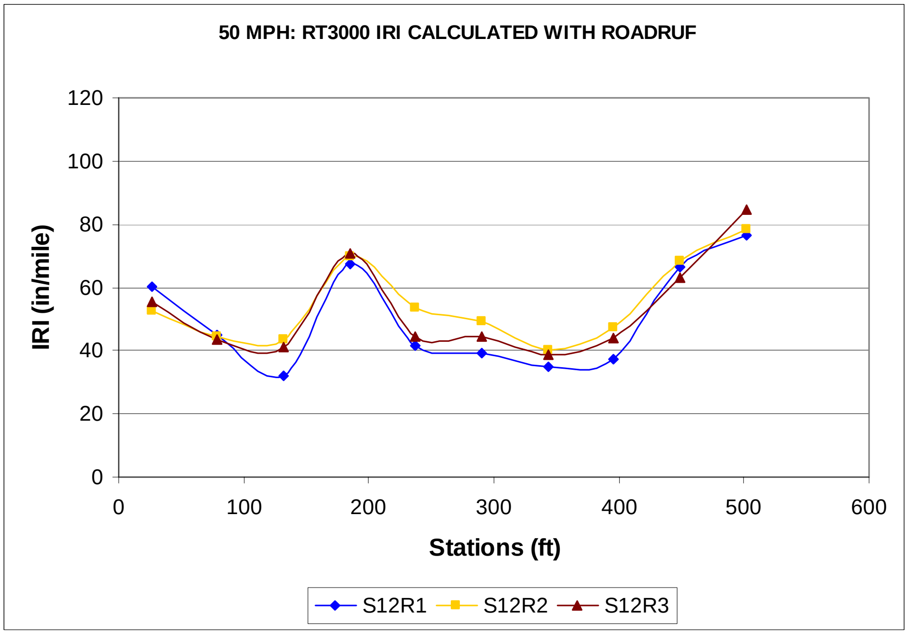


Figure B300: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

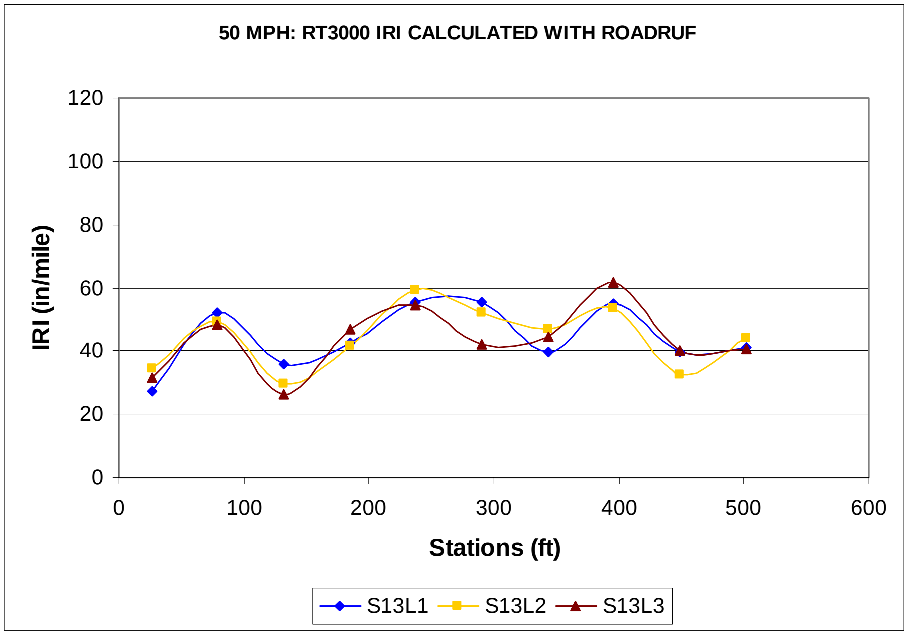


Figure B301: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

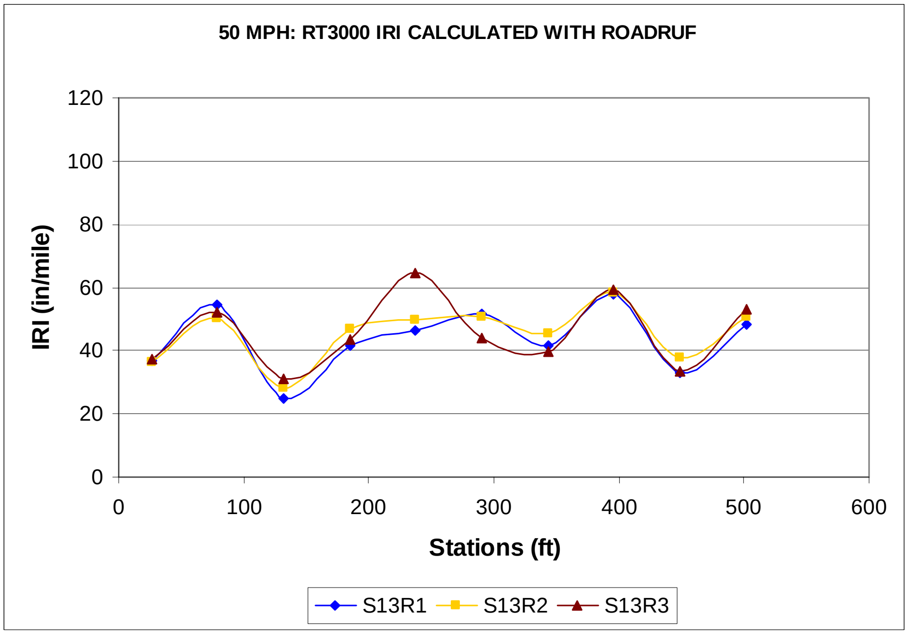


Figure B302: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

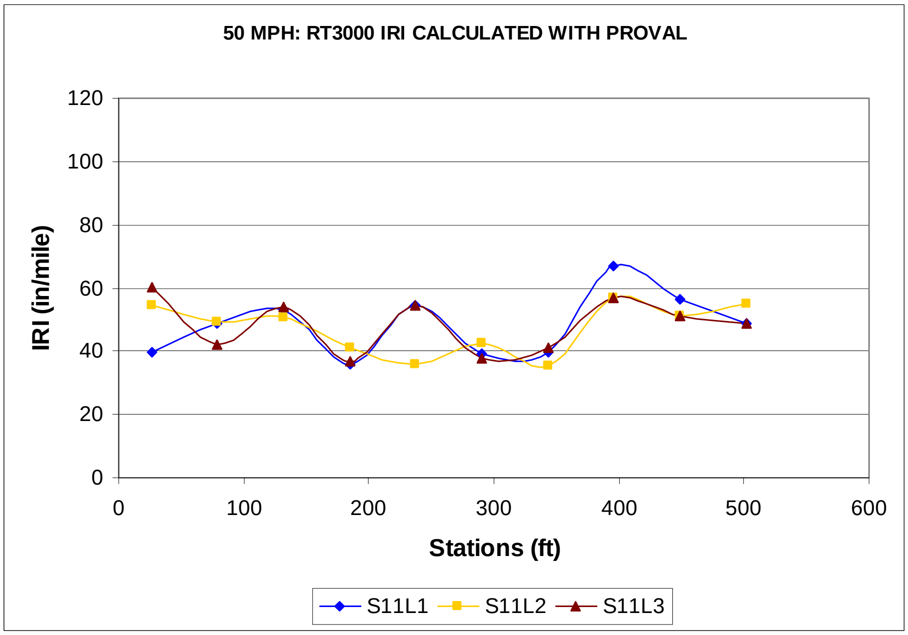


Figure B303: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

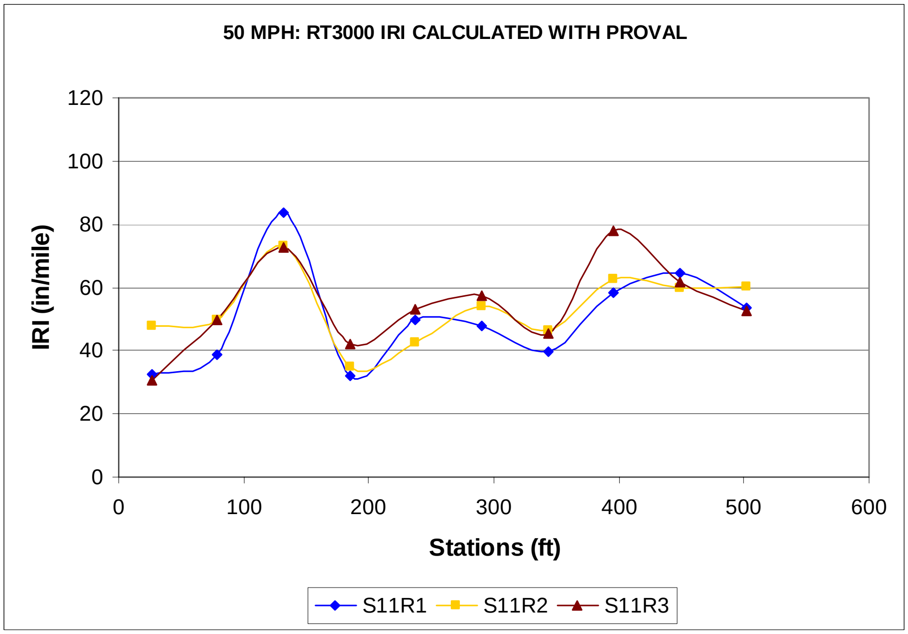


Figure B304: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

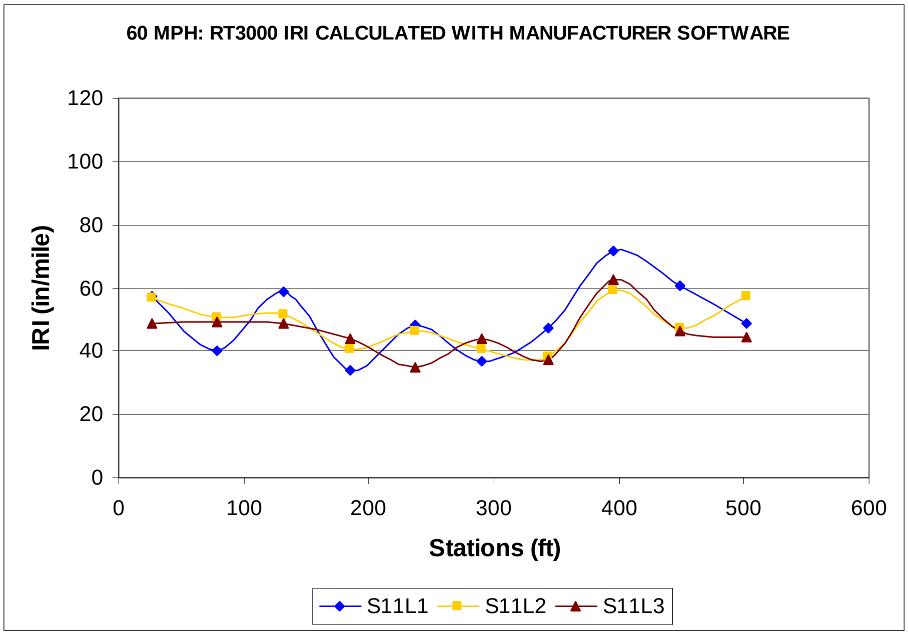


Figure B305: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

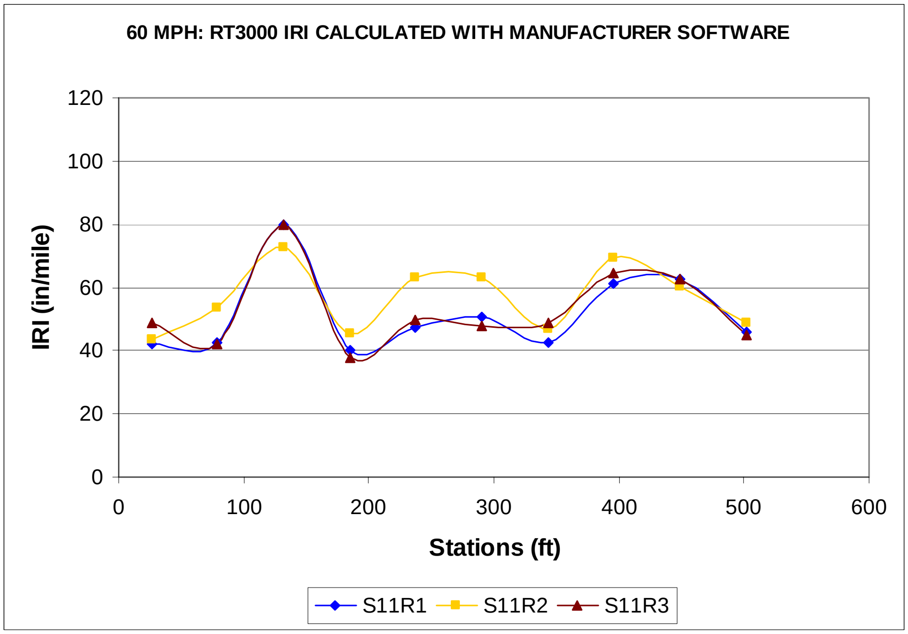


Figure B306: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

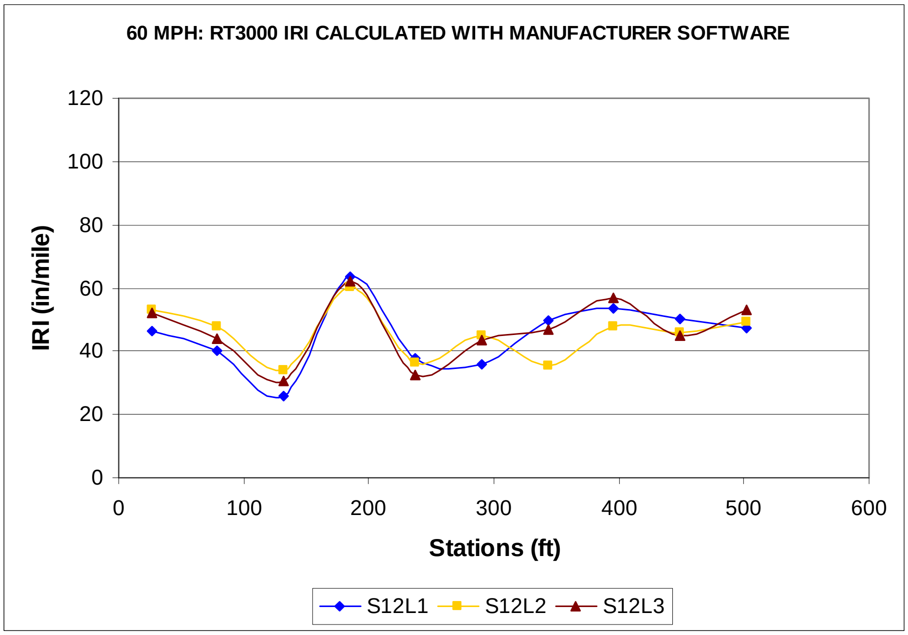


Figure B307: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

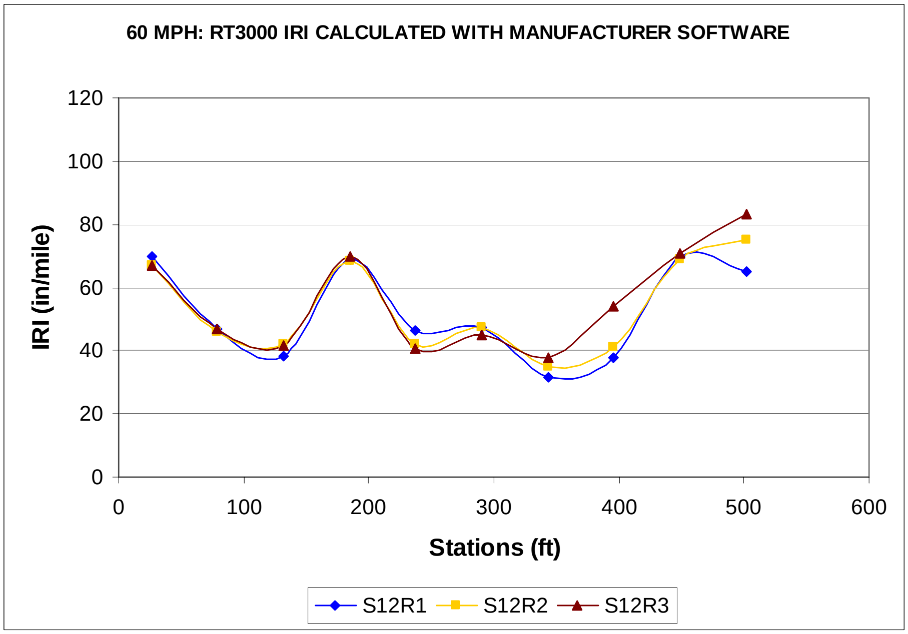


Figure B308: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

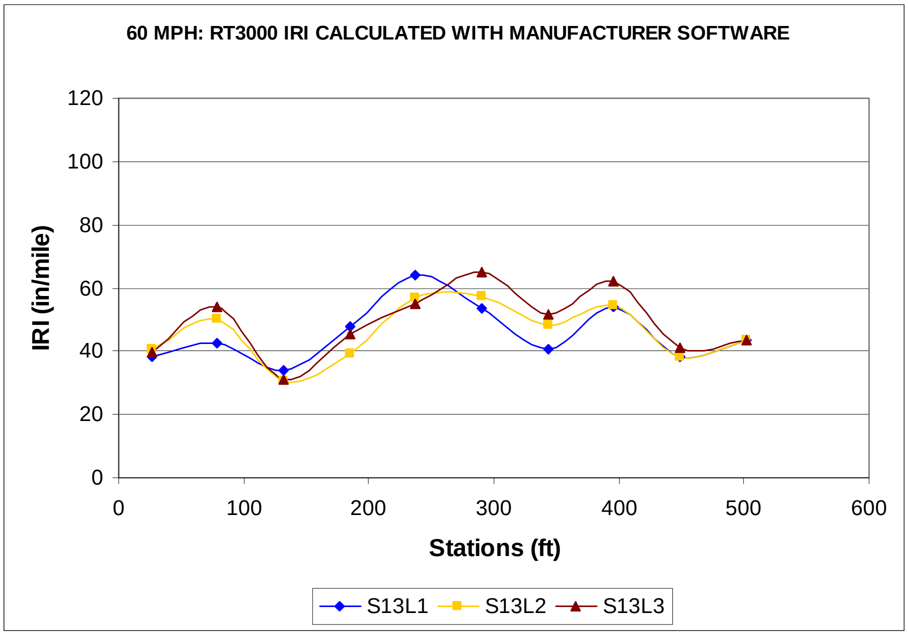


Figure B309: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

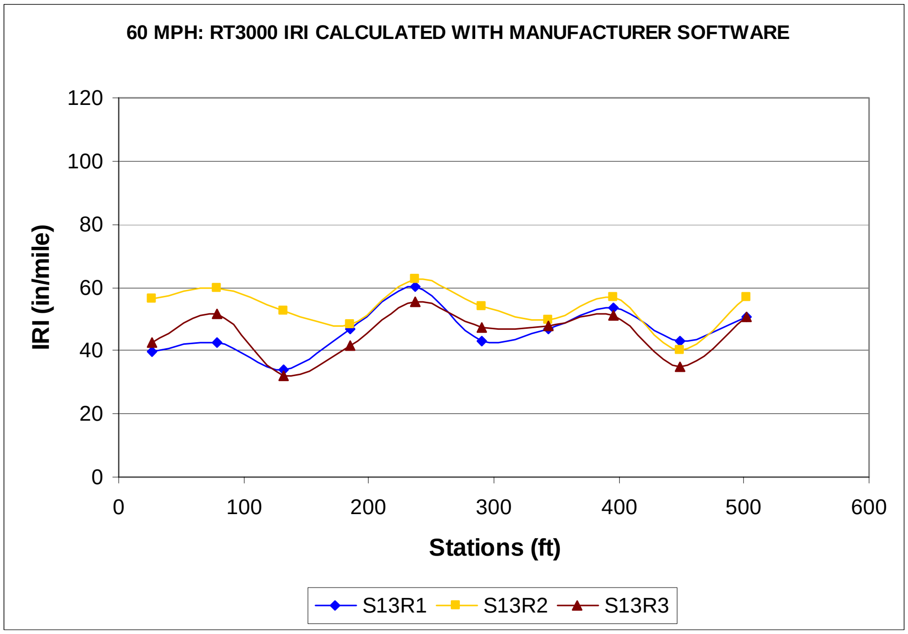


Figure B310: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

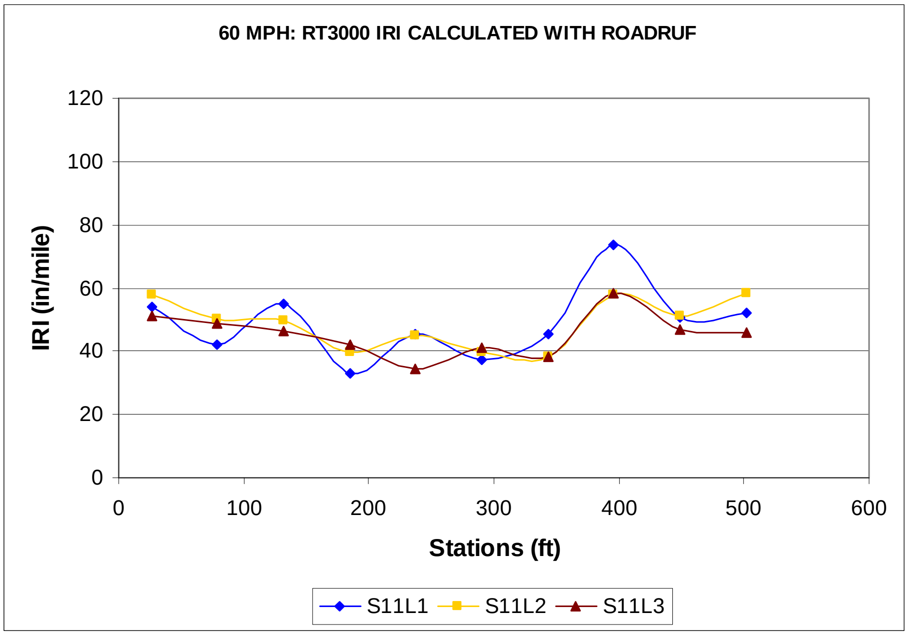


Figure B311: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

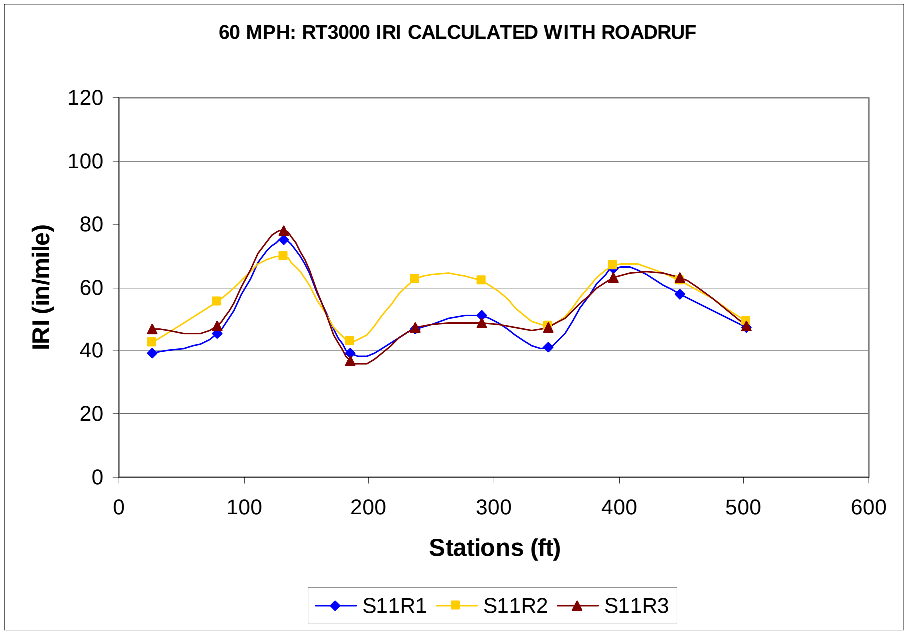


Figure B312: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

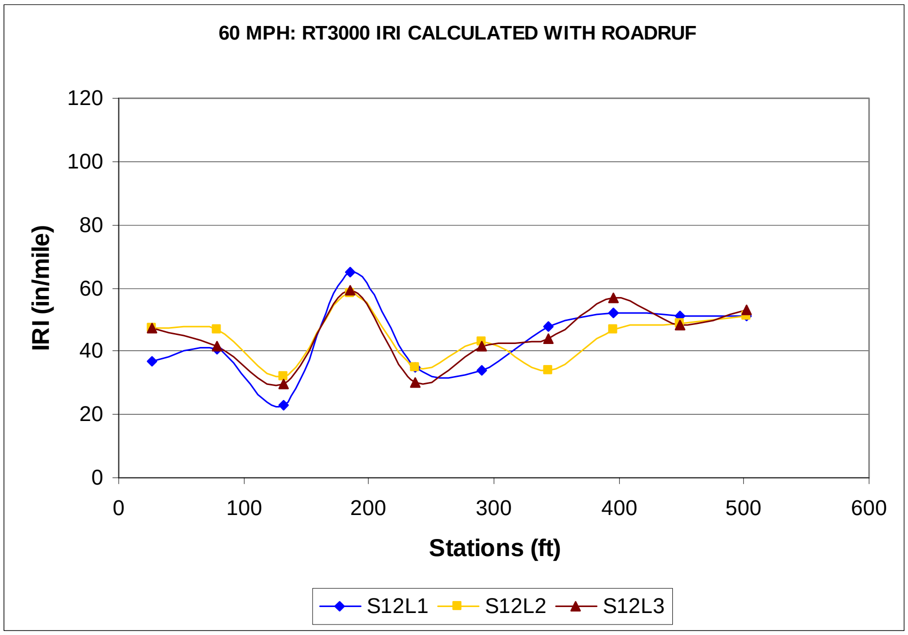


Figure B313: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

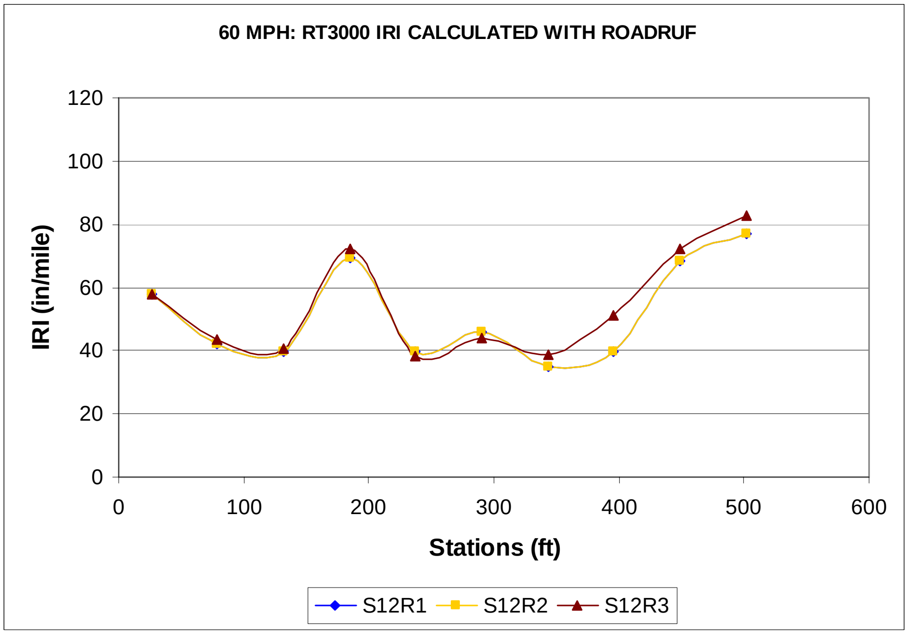


Figure B314: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

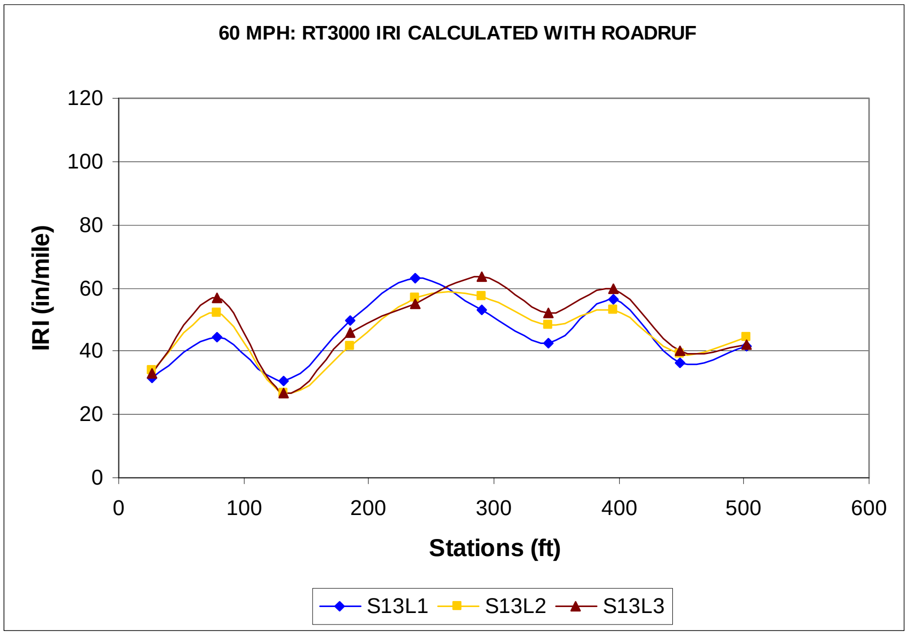


Figure B315: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

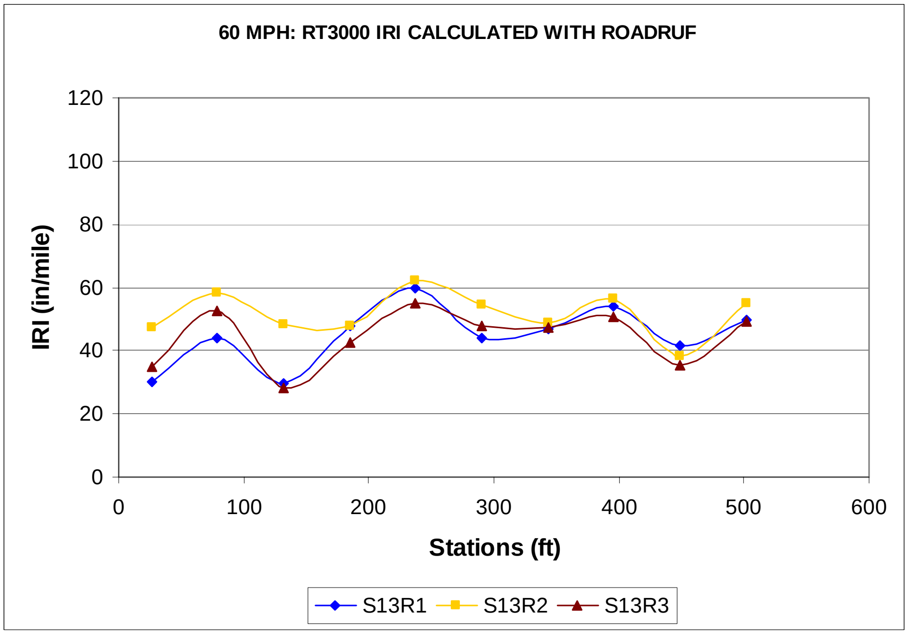


Figure B316: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

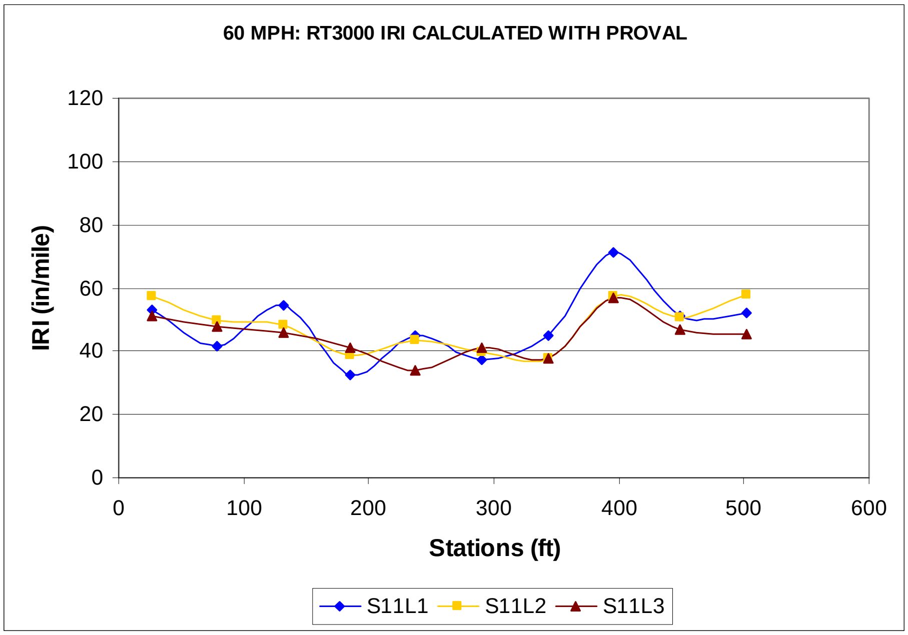


Figure B317: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

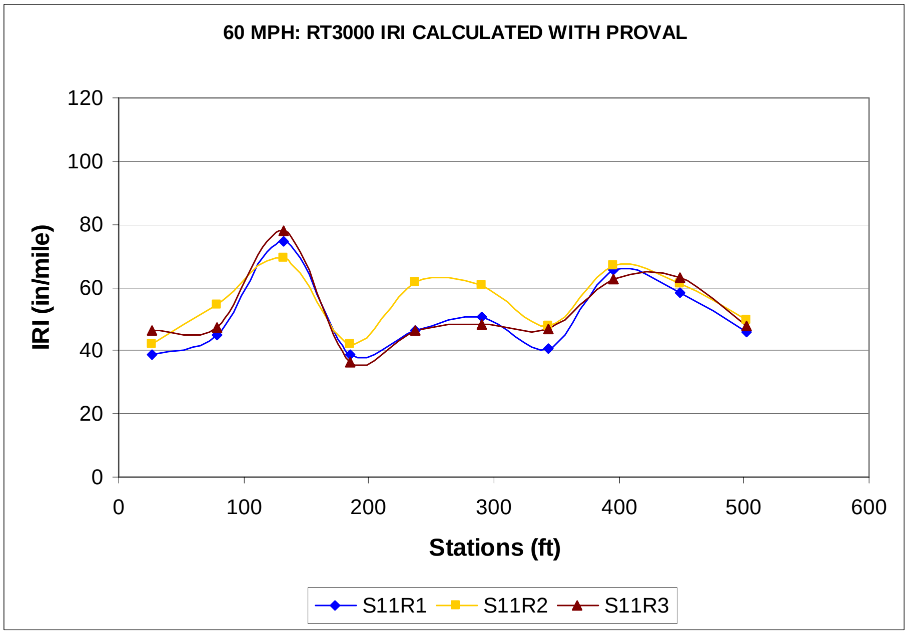


Figure B318: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

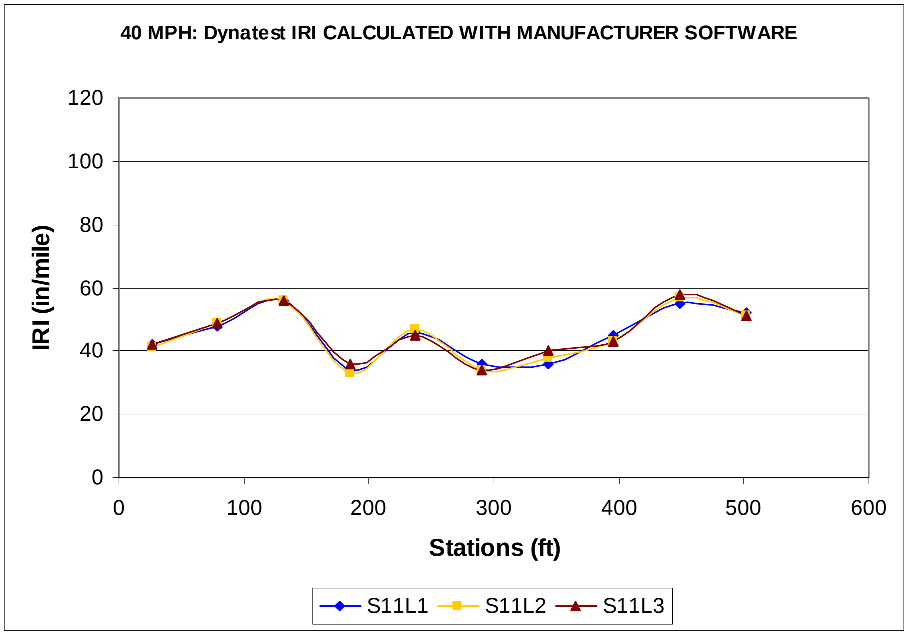


Figure B319: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

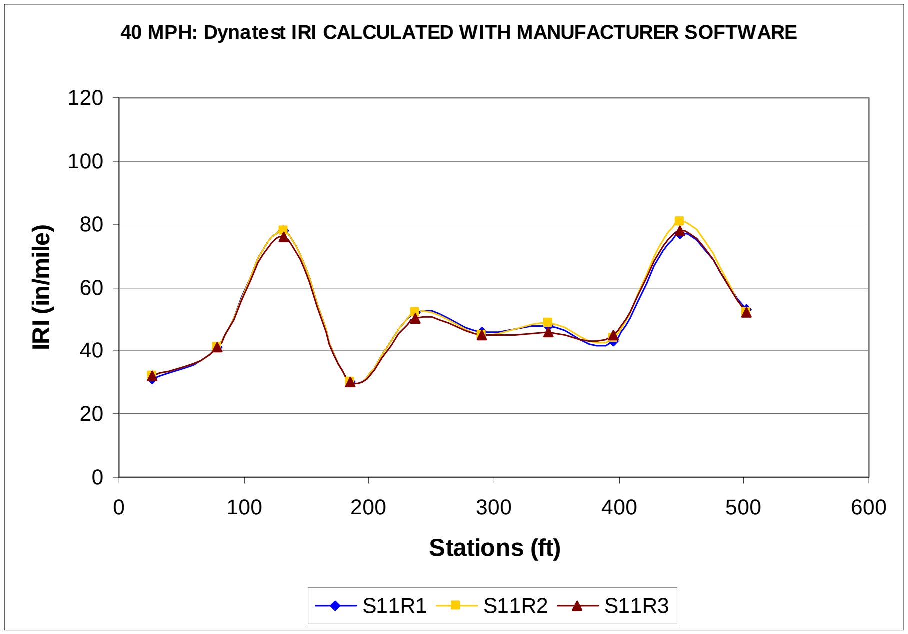


Figure B320: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

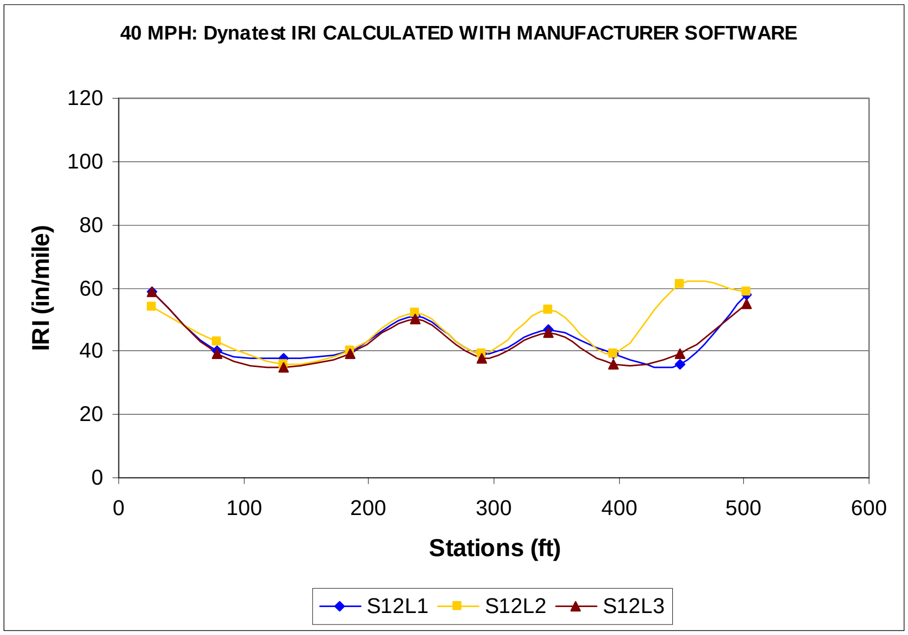


Figure B321: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

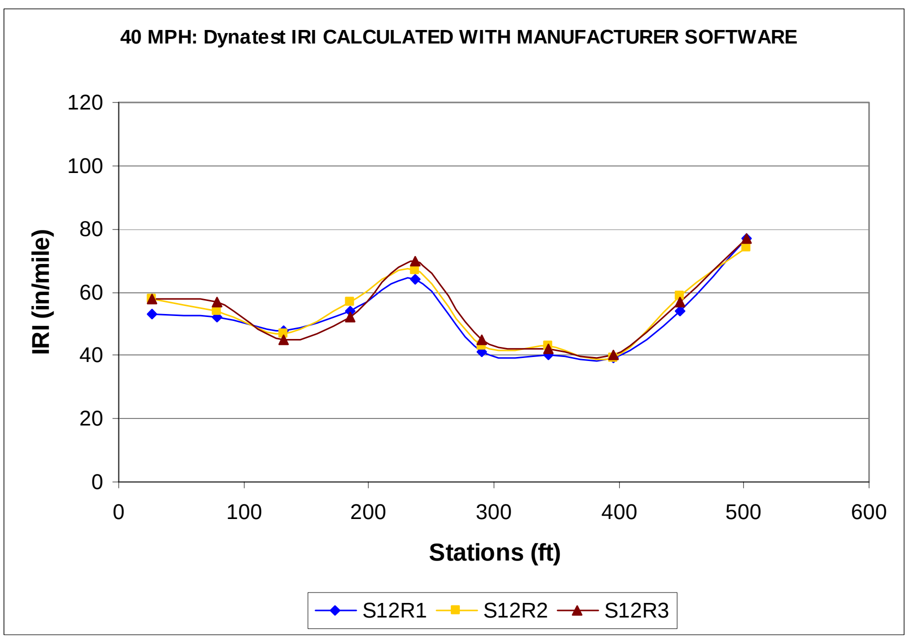


Figure B322: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

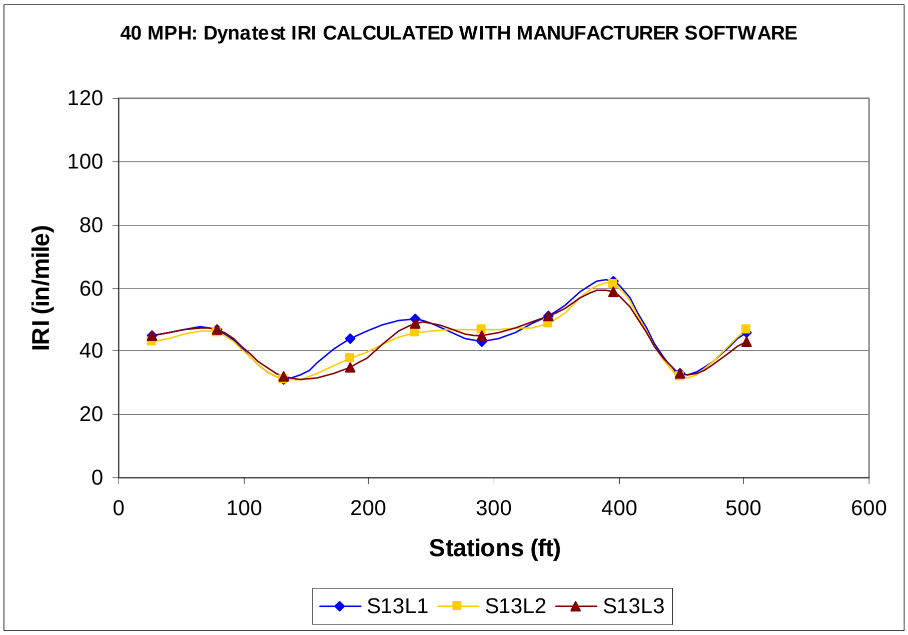


Figure B323: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

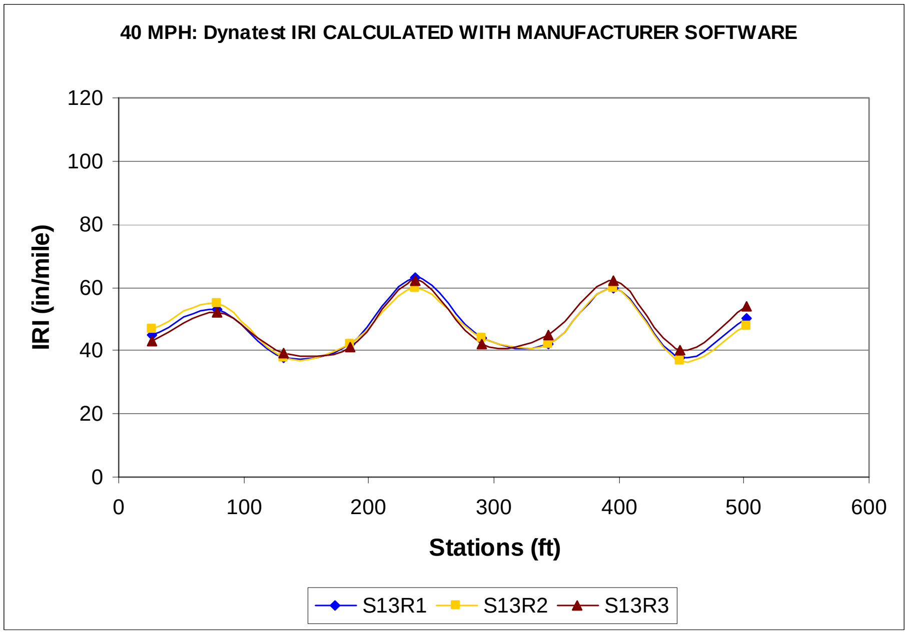


Figure B324: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

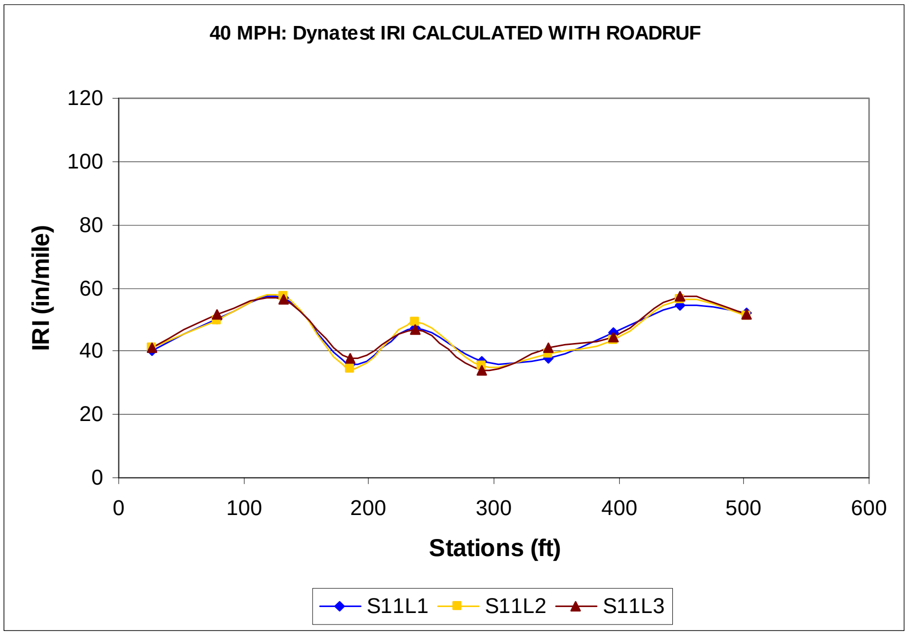


Figure B325: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

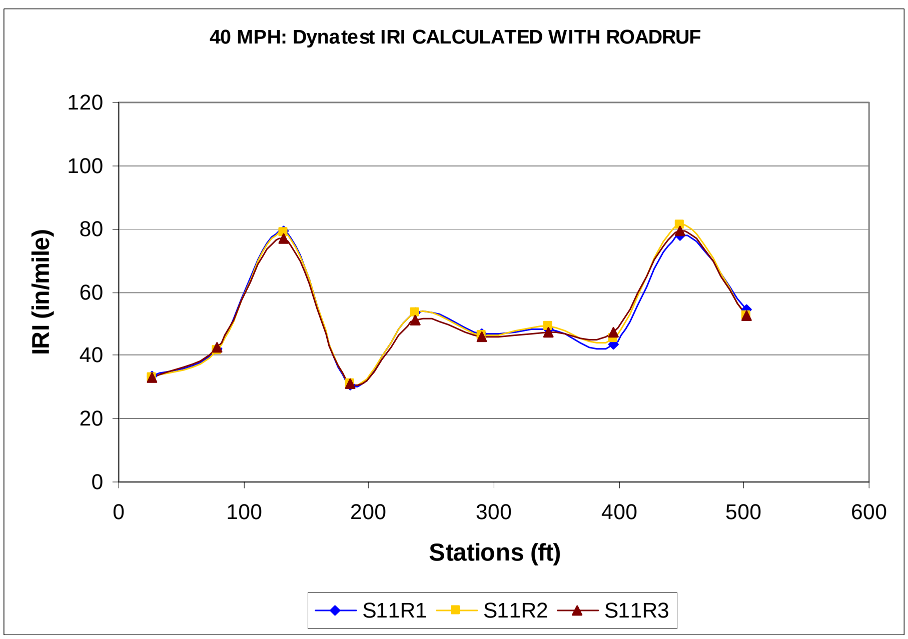


Figure B326: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

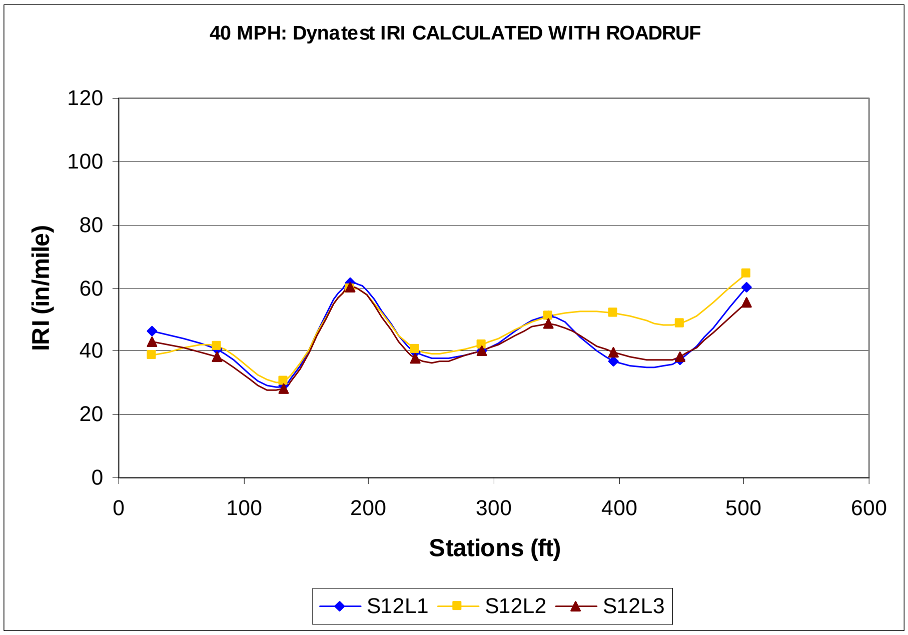


Figure B327: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

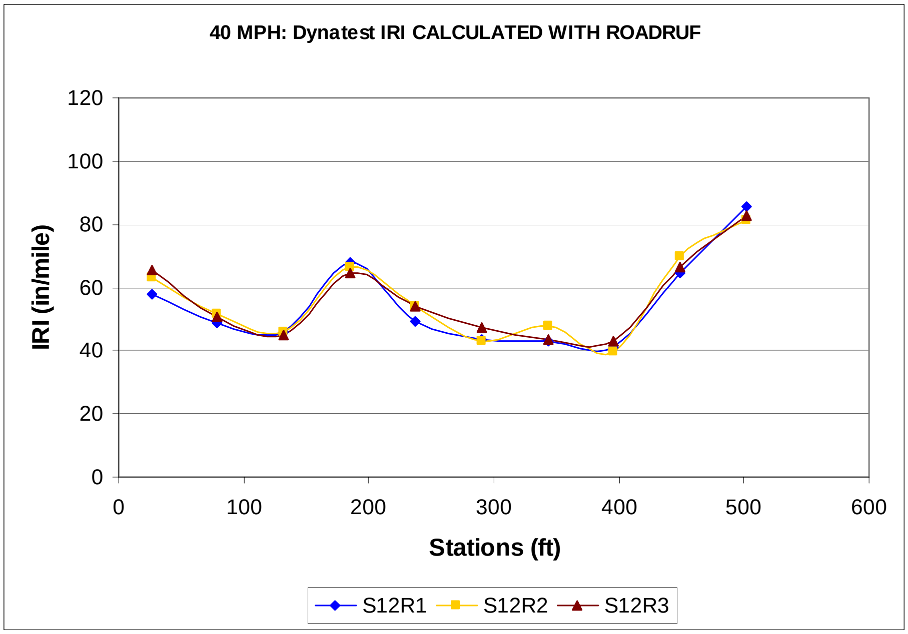


Figure B328: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

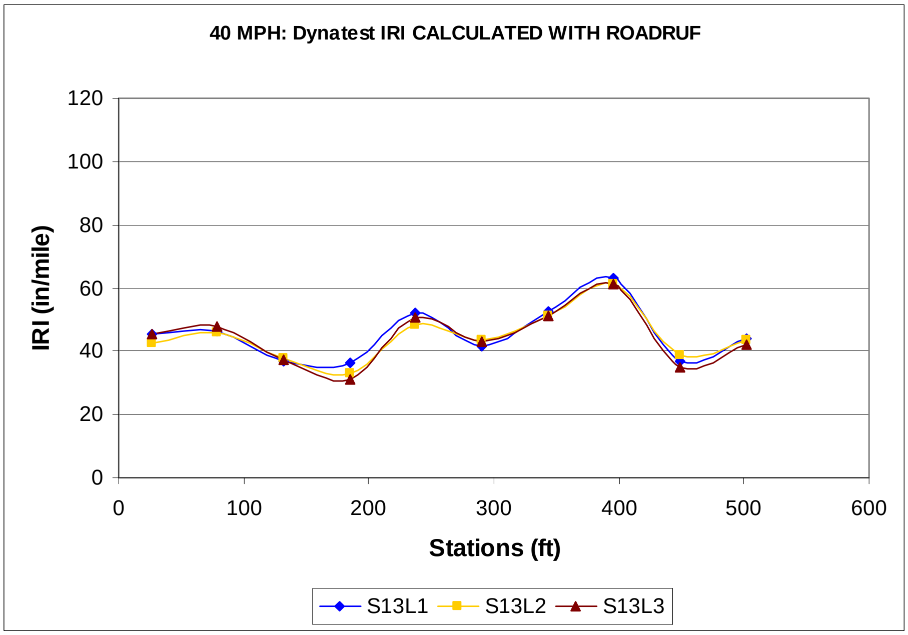


Figure B329: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

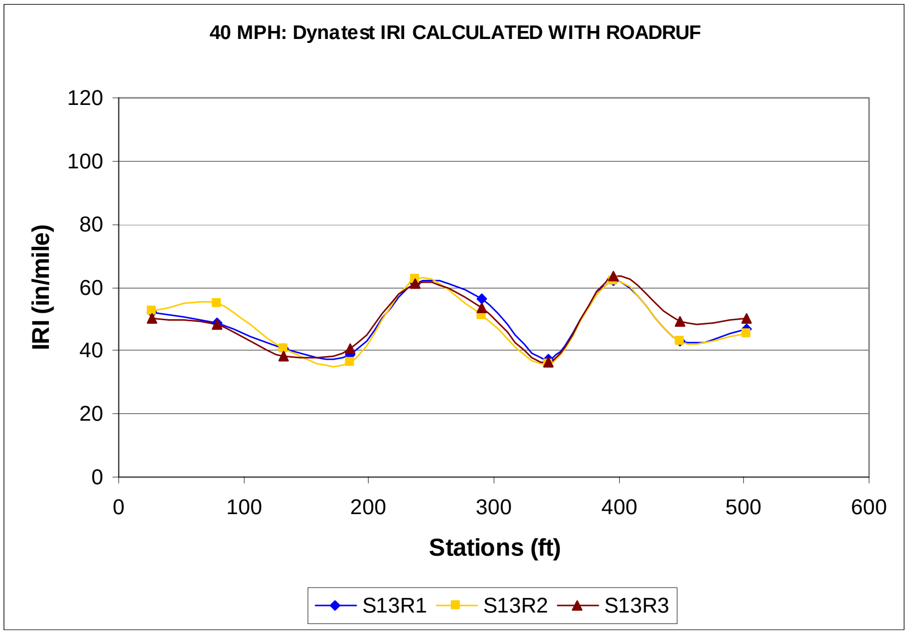


Figure B330: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

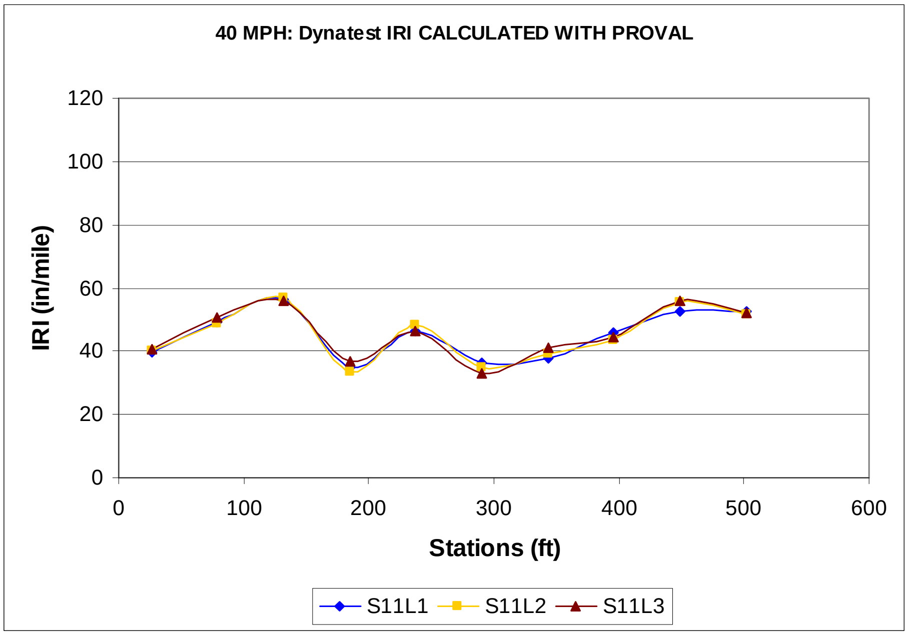


Figure B331: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

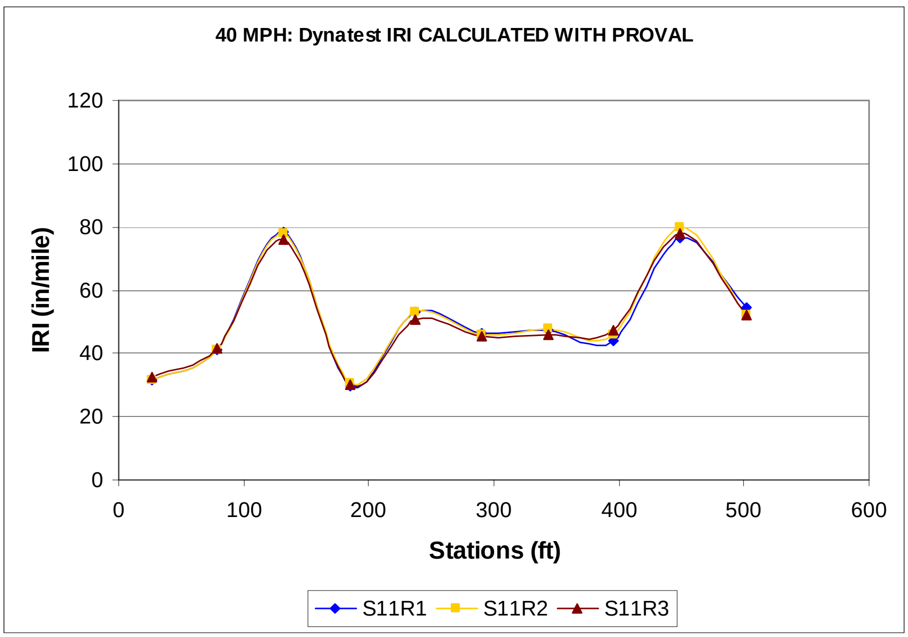


Figure B332: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

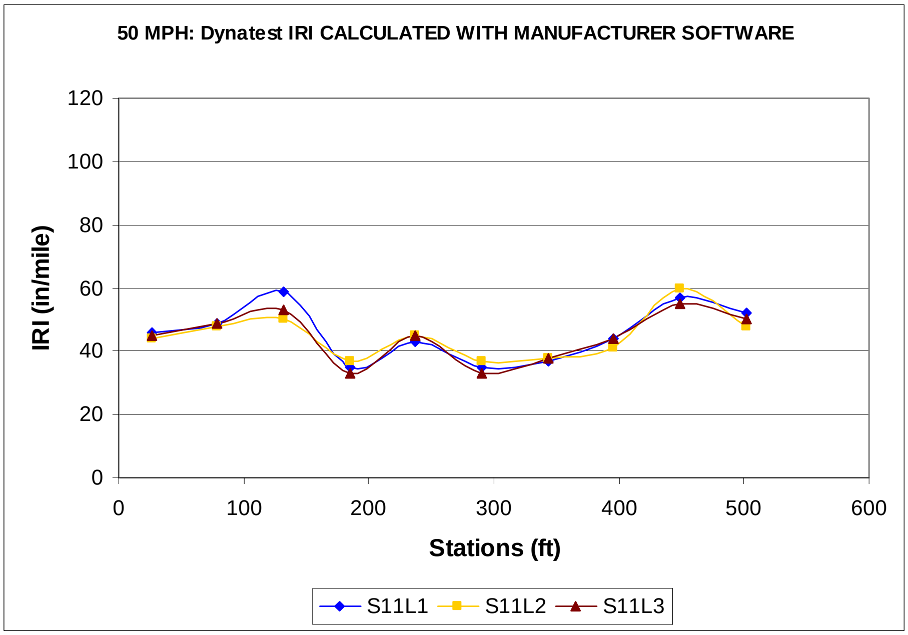


Figure B333: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

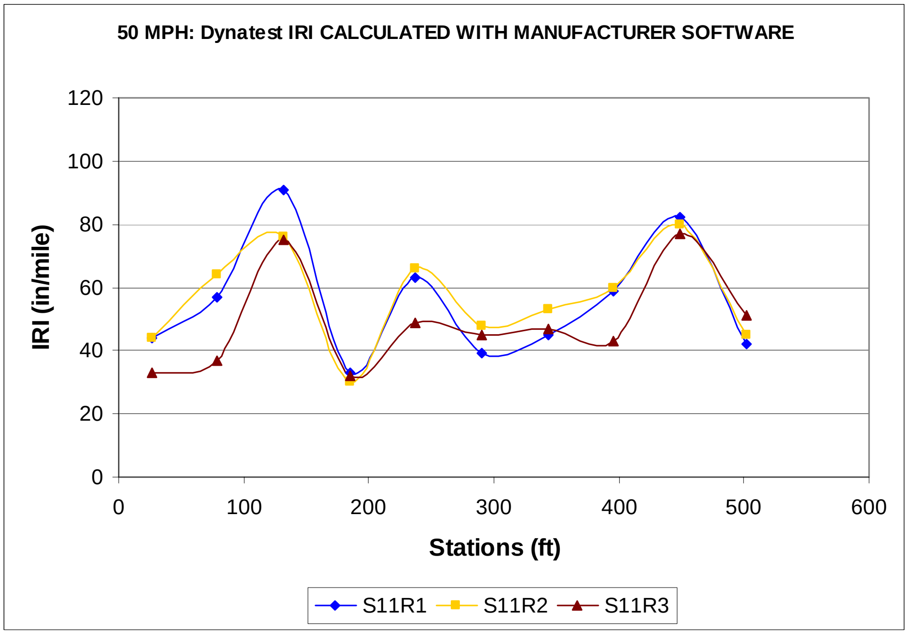


Figure B334: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

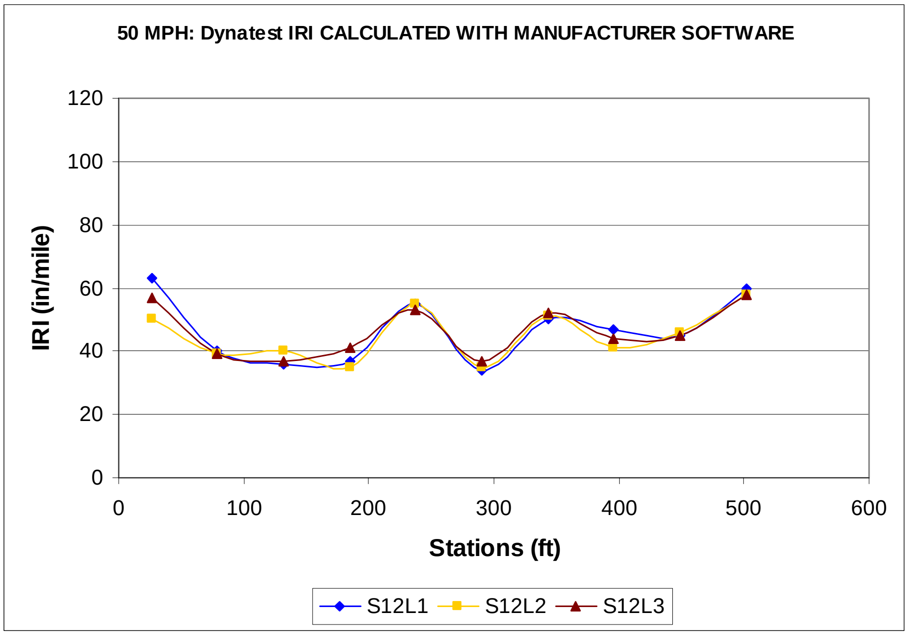


Figure B335: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

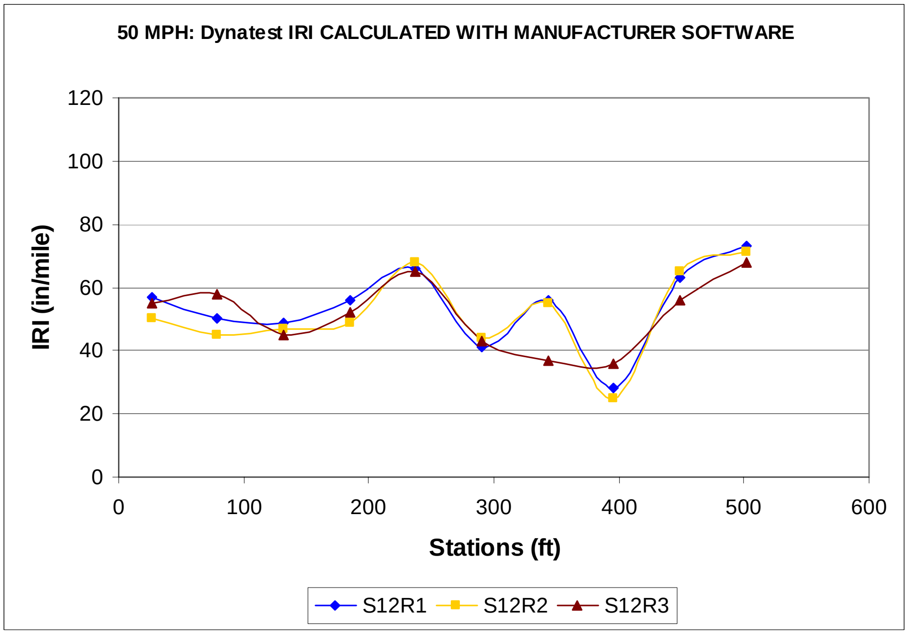


Figure B336: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

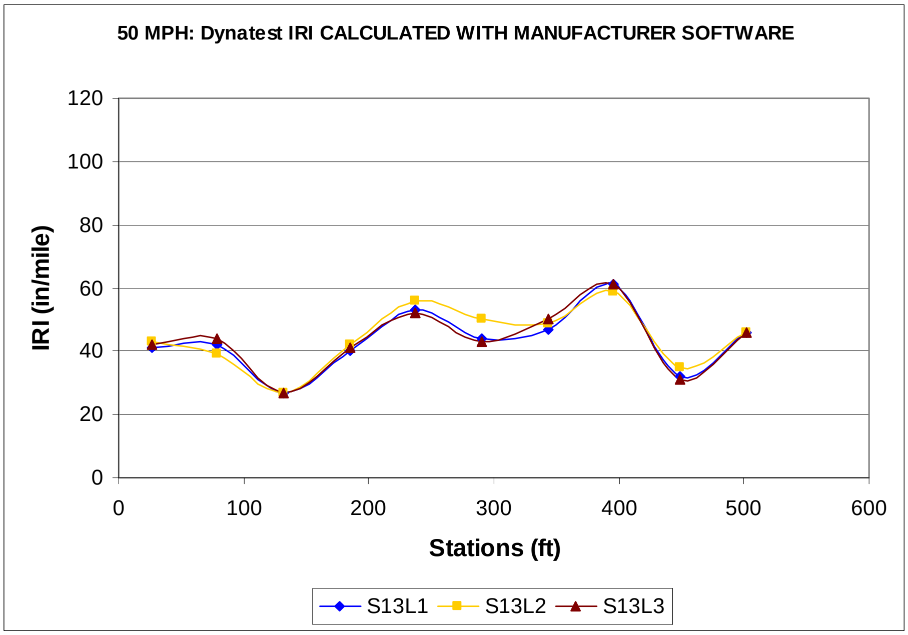


Figure B337: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

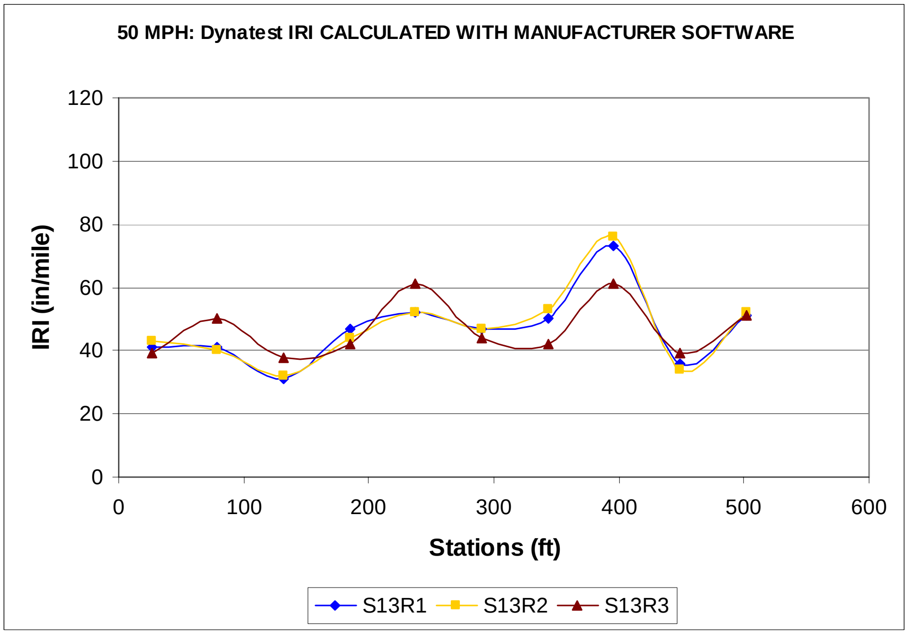


Figure B338: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

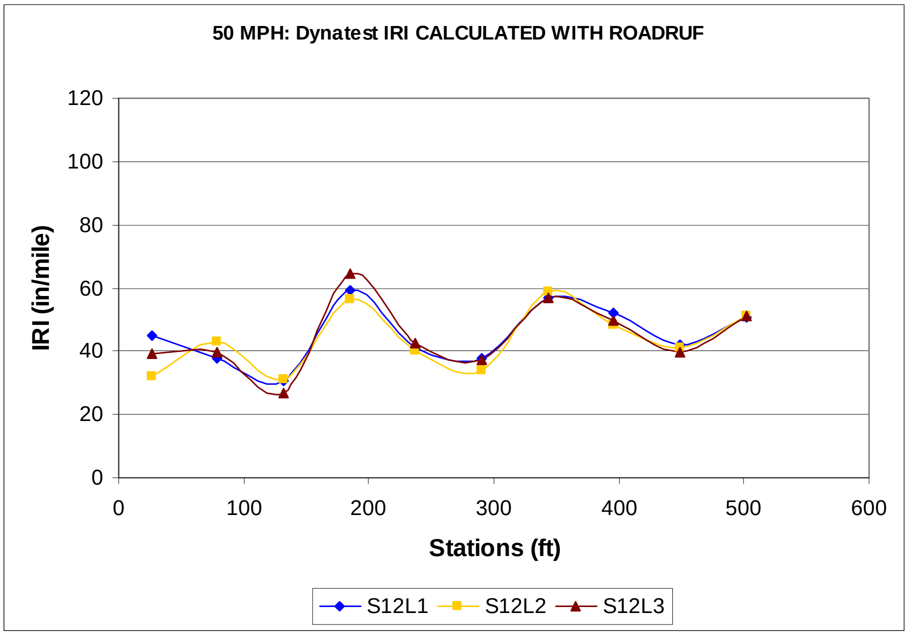


Figure B339: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

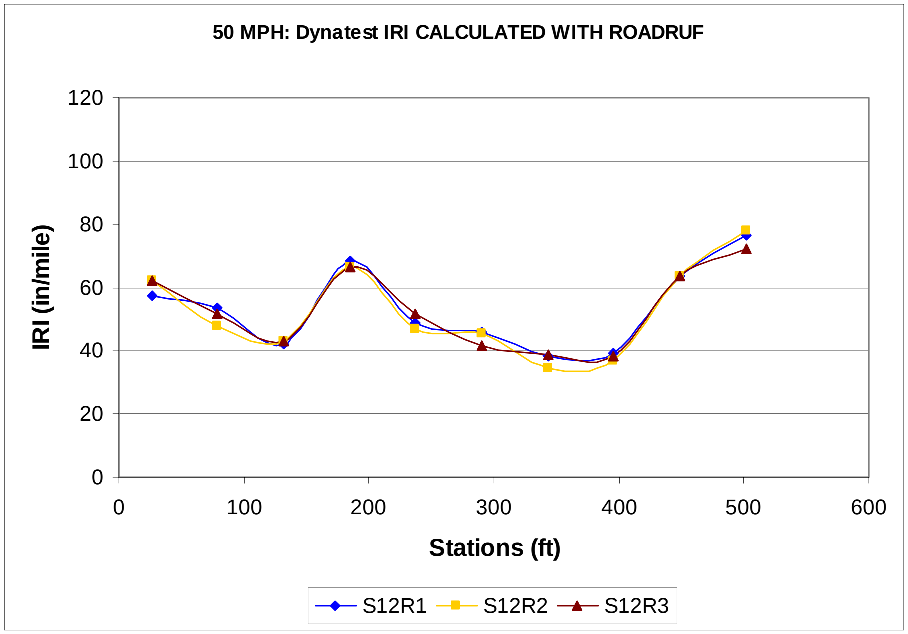


Figure B340: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

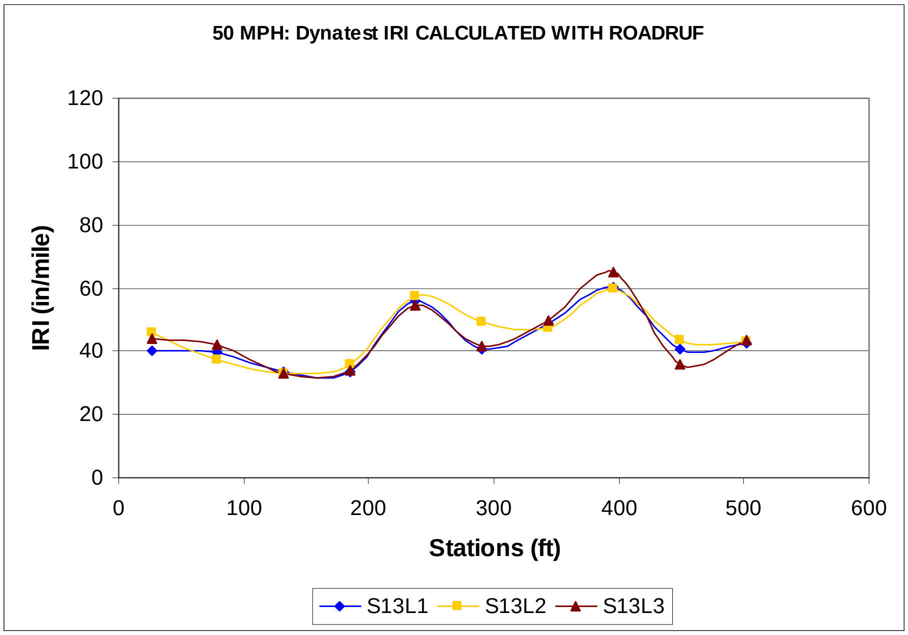


Figure B341: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

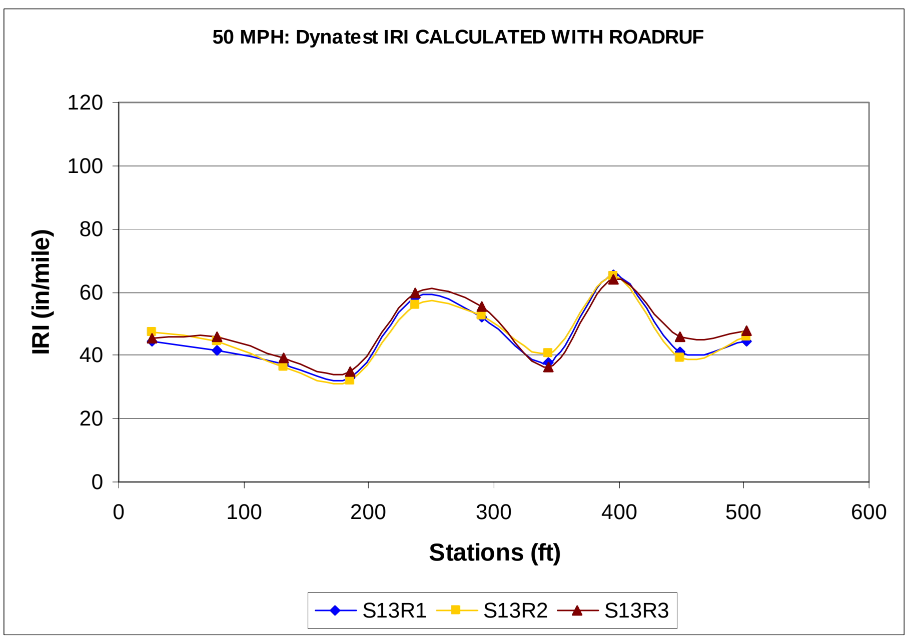


Figure B342: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

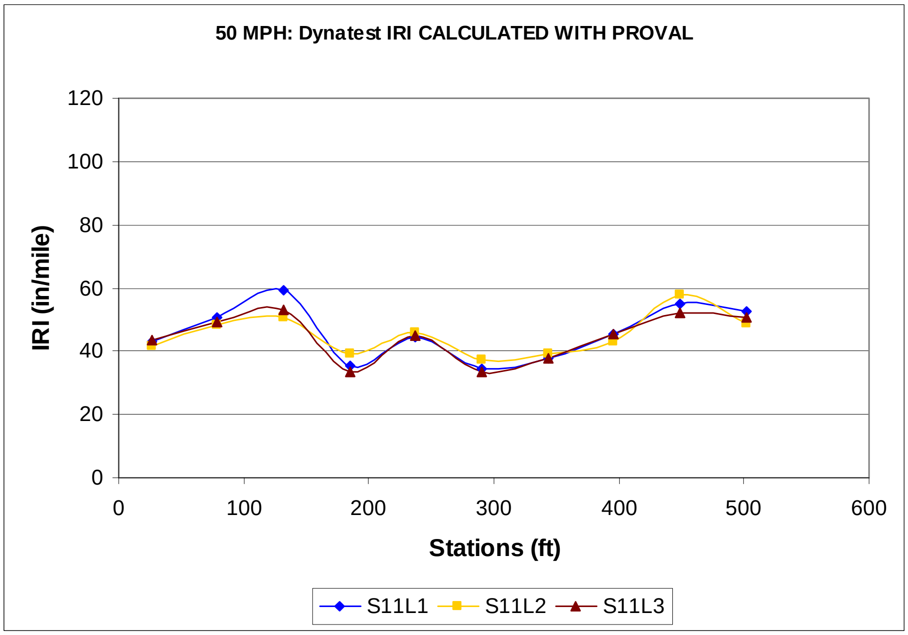


Figure B343: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

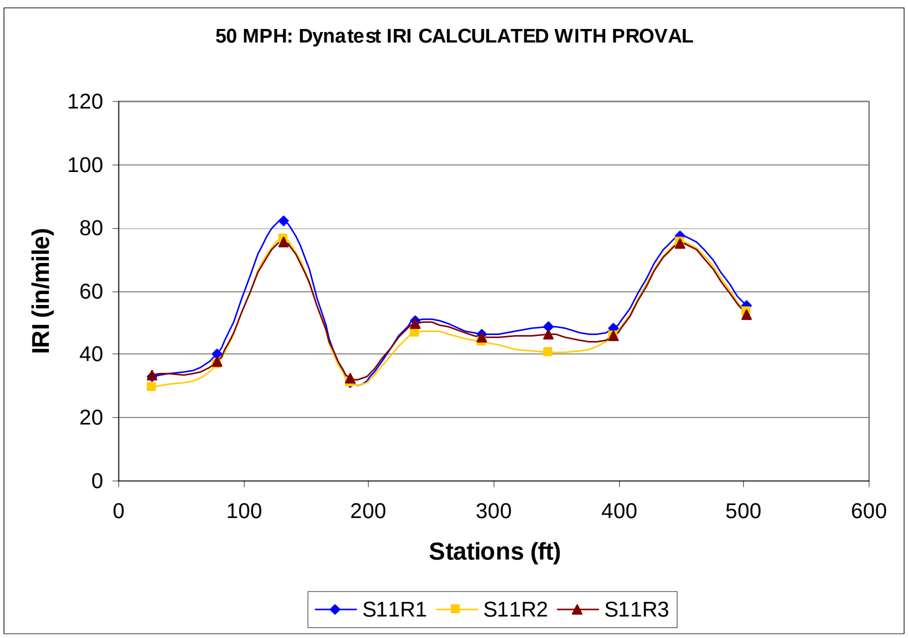


Figure B344: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

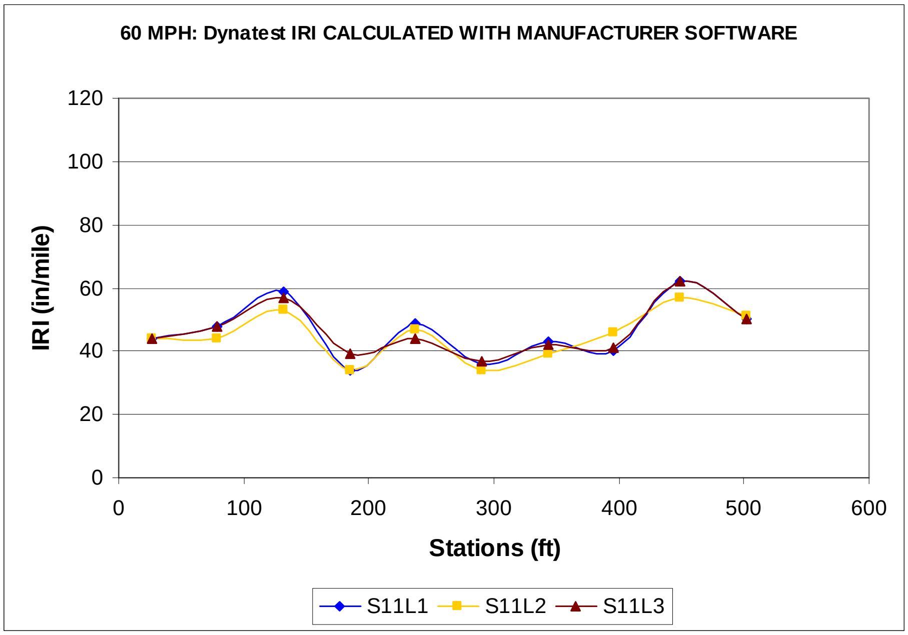


Figure B345: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

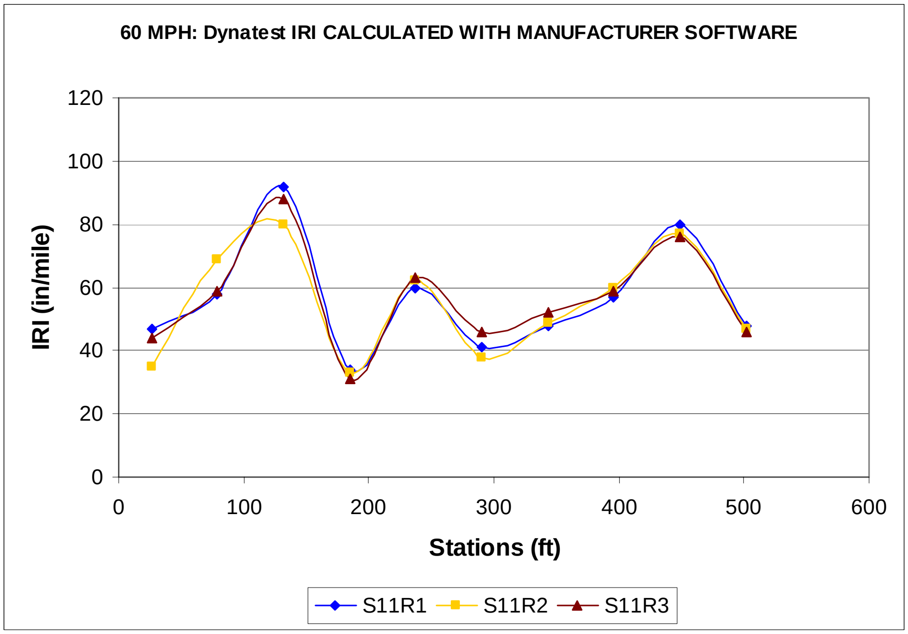


Figure B346: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

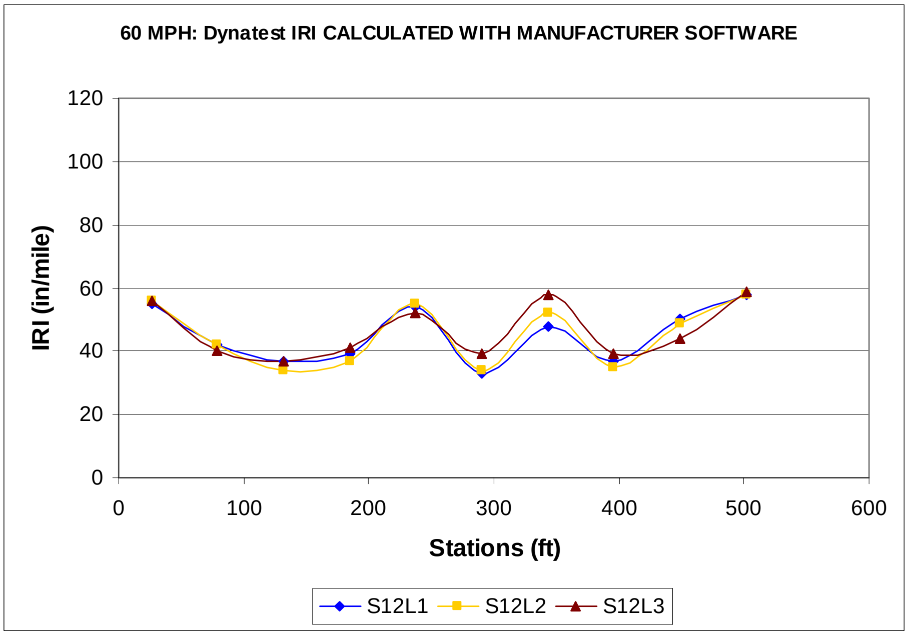


Figure B347: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

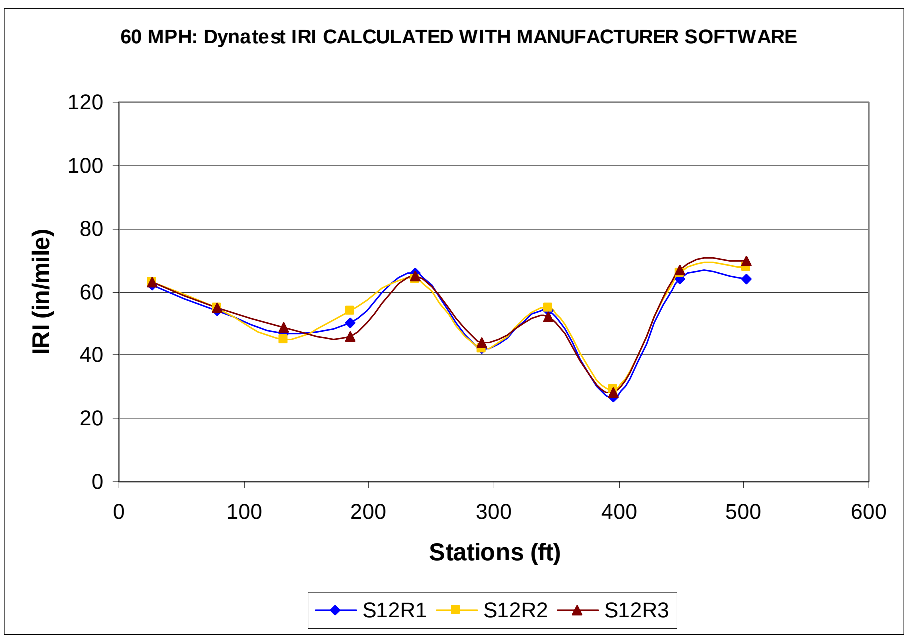


Figure B348: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

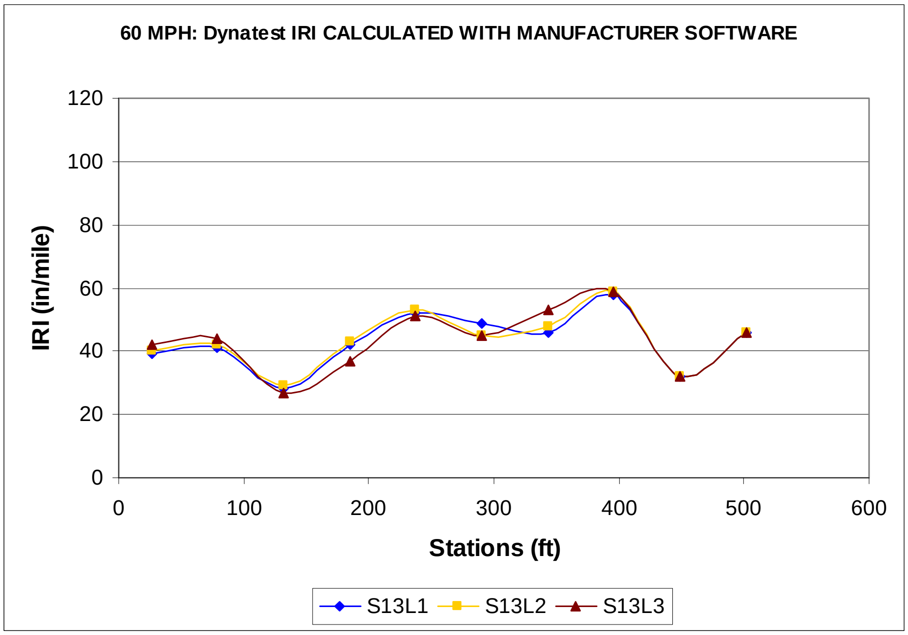


Figure B349: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

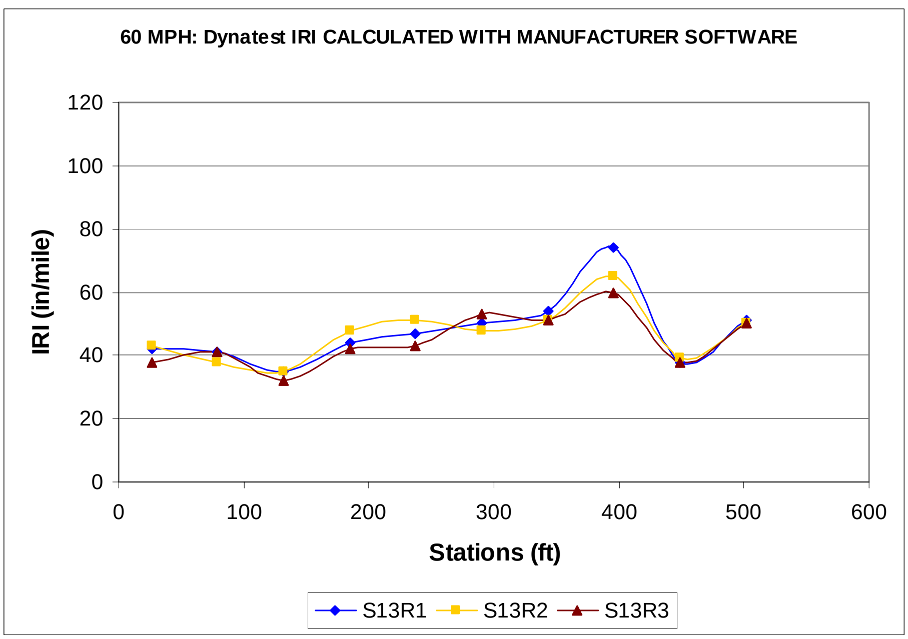


Figure B350: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

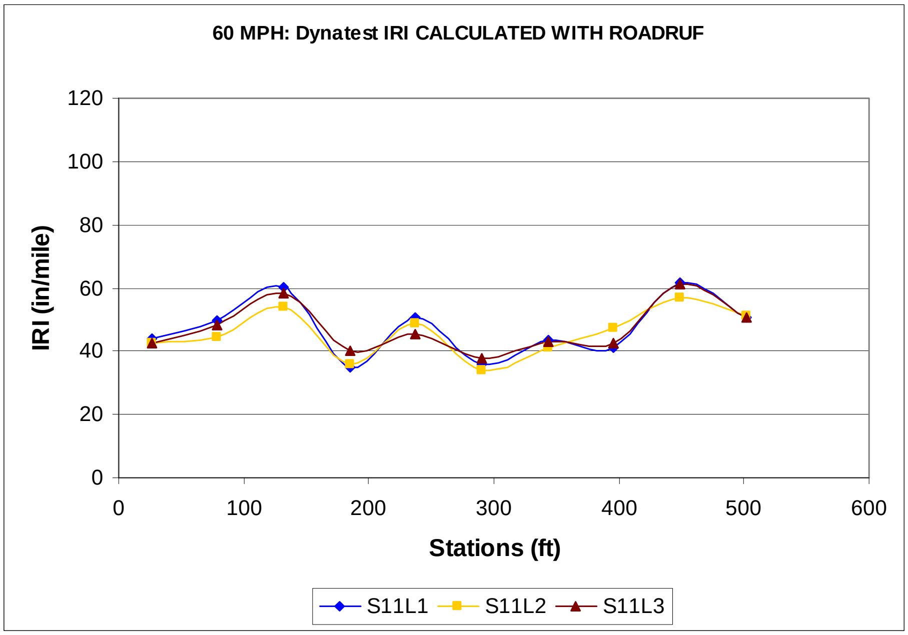


Figure B351: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

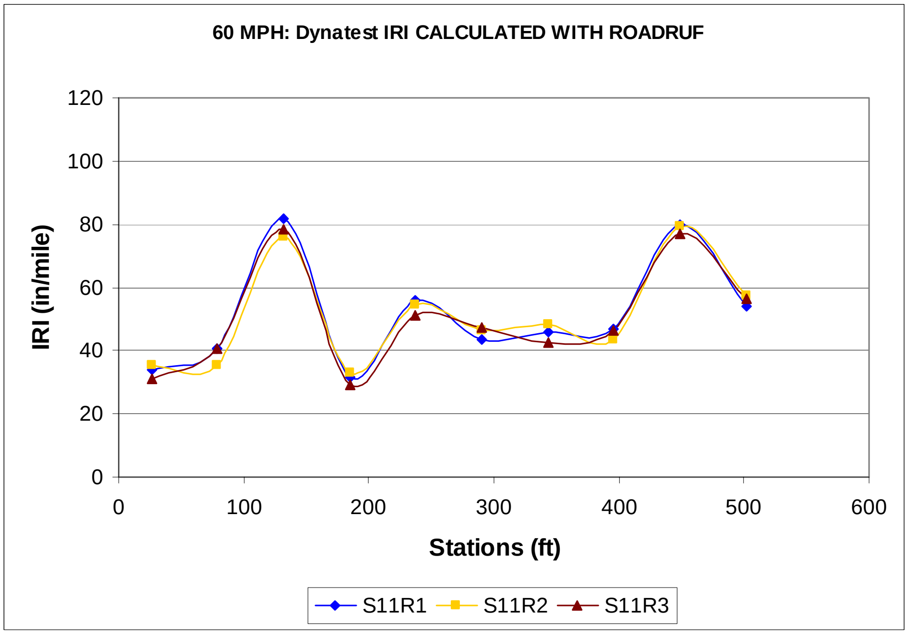


Figure B352: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

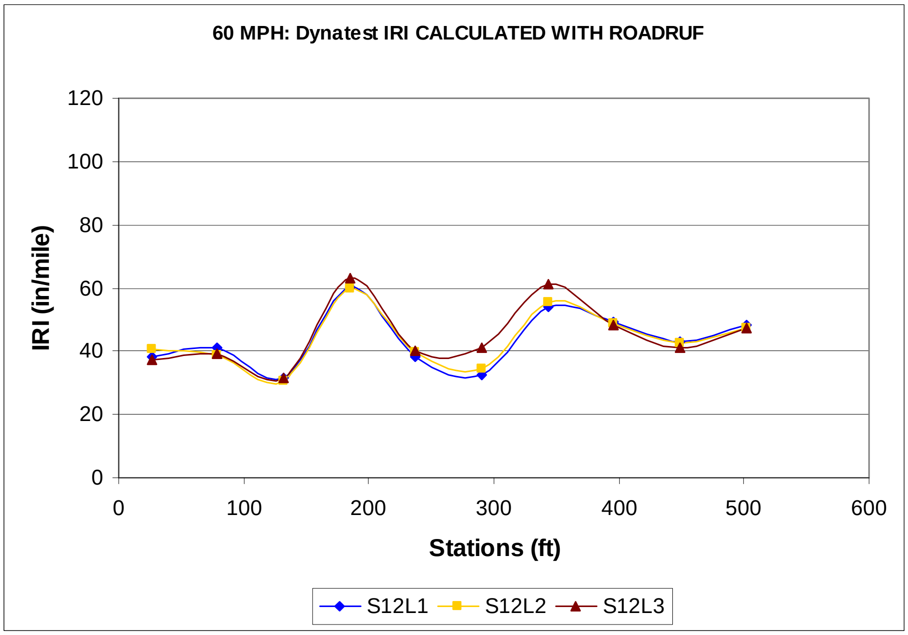


Figure B353: IRI, Route 55, Very Smooth, Section 12, Left Wheel Path

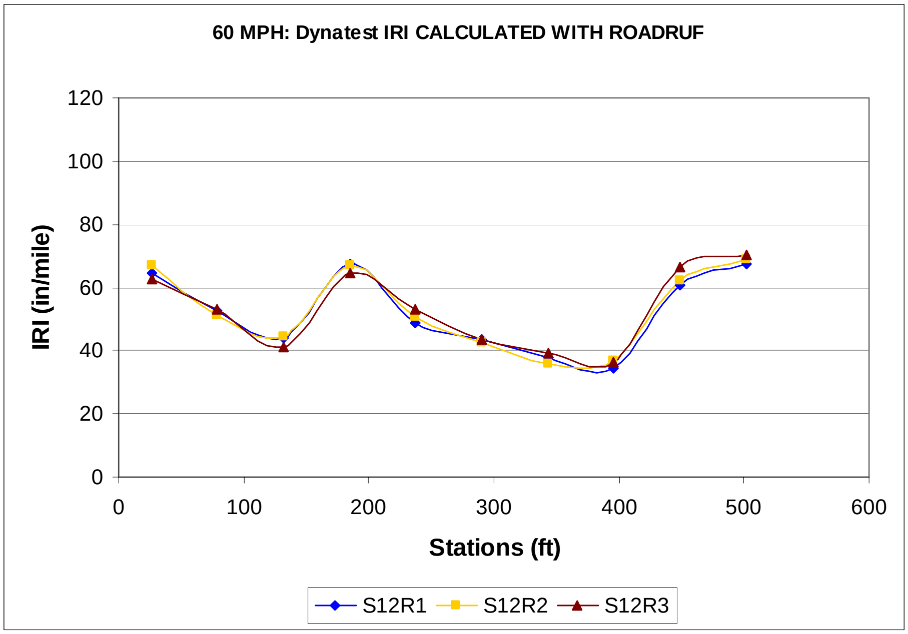


Figure B354: IRI, Route 55, Very Smooth, Section 12, Right Wheel Path

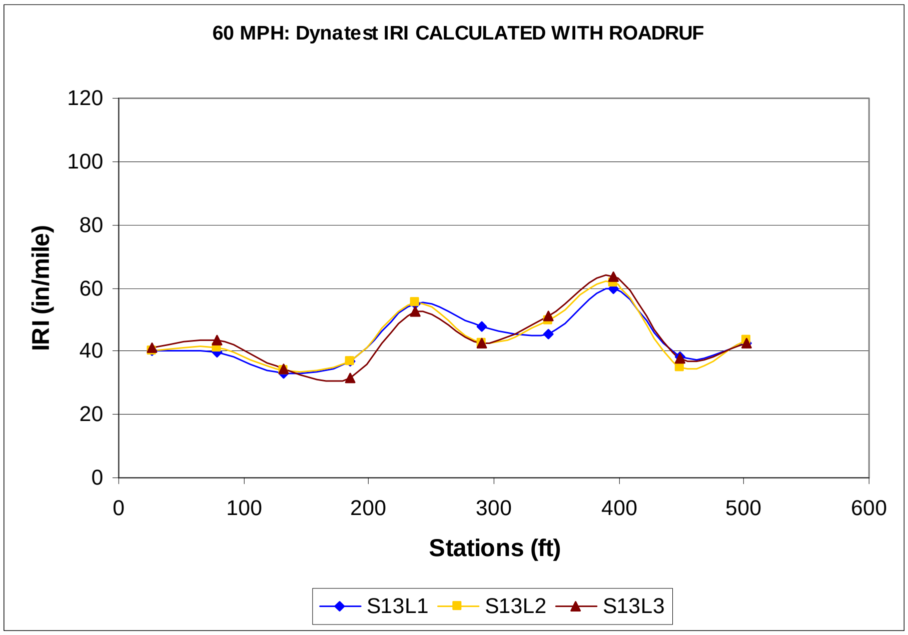


Figure B355: IRI, Route 55, Very Smooth, Section 13, Left Wheel Path

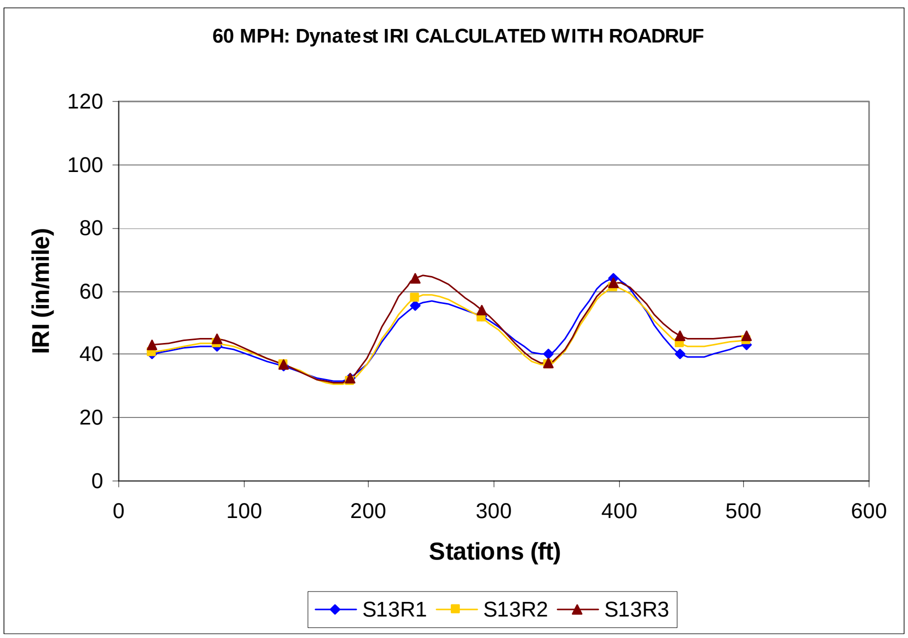


Figure B356: IRI, Route 55, Very Smooth, Section 13, Right Wheel Path

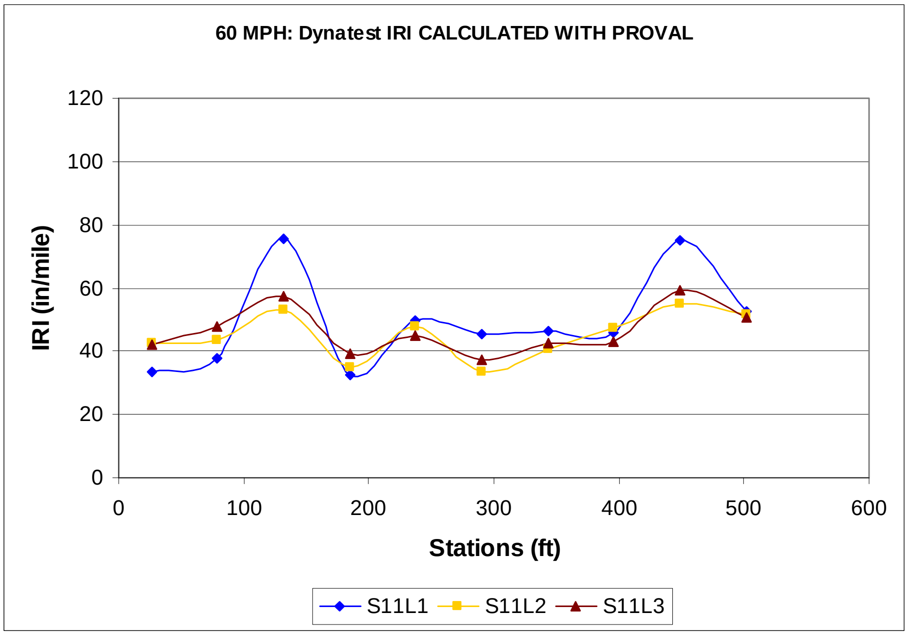


Figure B357: IRI, Route 55, Very Smooth, Section 11, Left Wheel Path

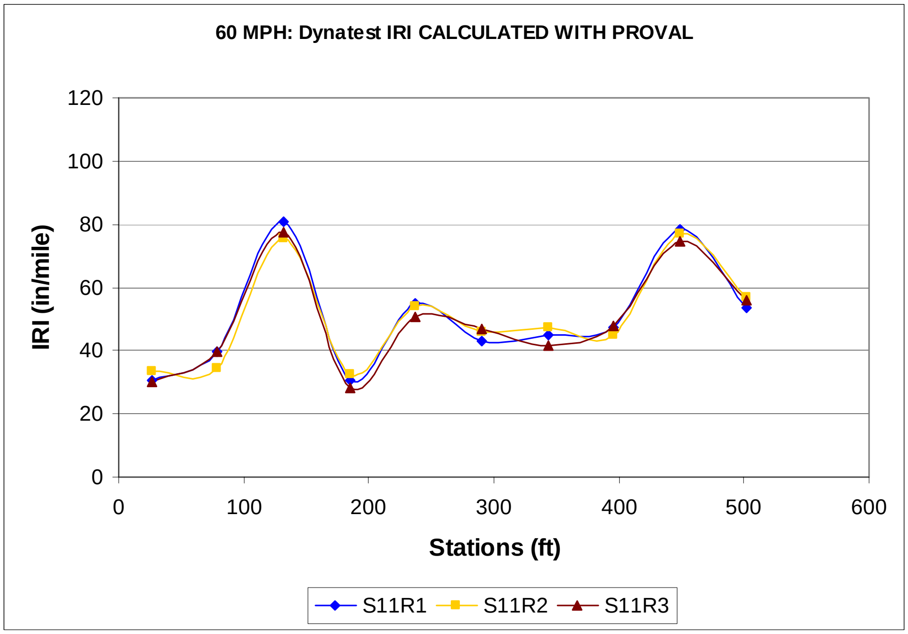


Figure B358: IRI, Route 55, Very Smooth, Section 11, Right Wheel Path

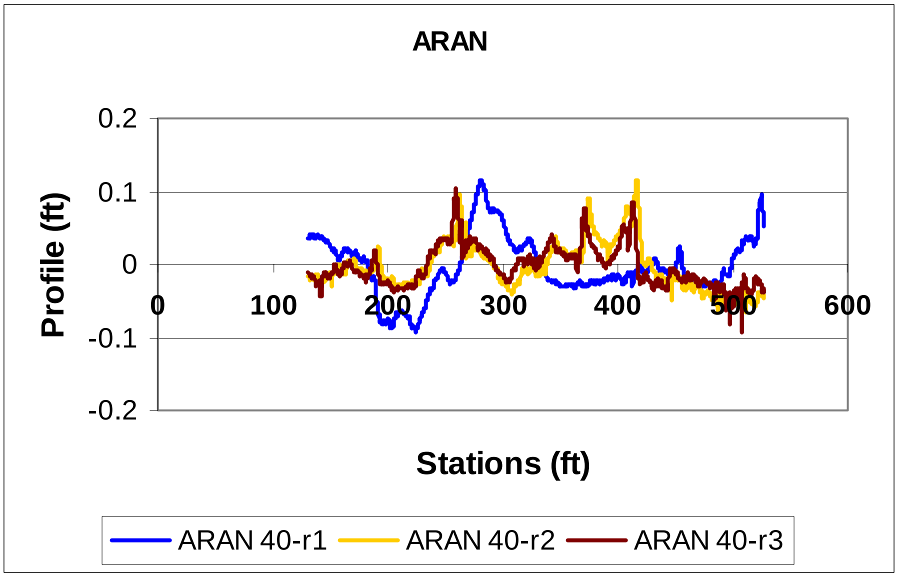


Figure B359: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

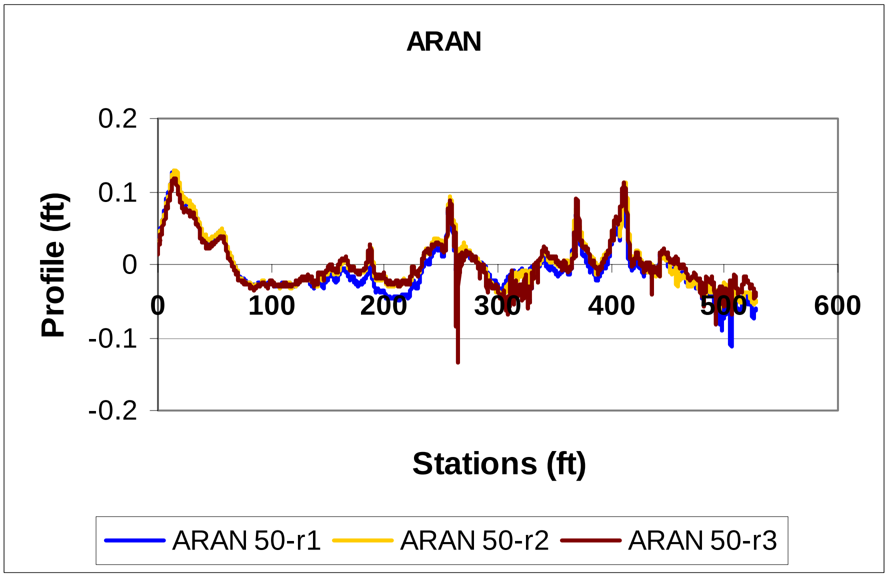


Figure B360: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

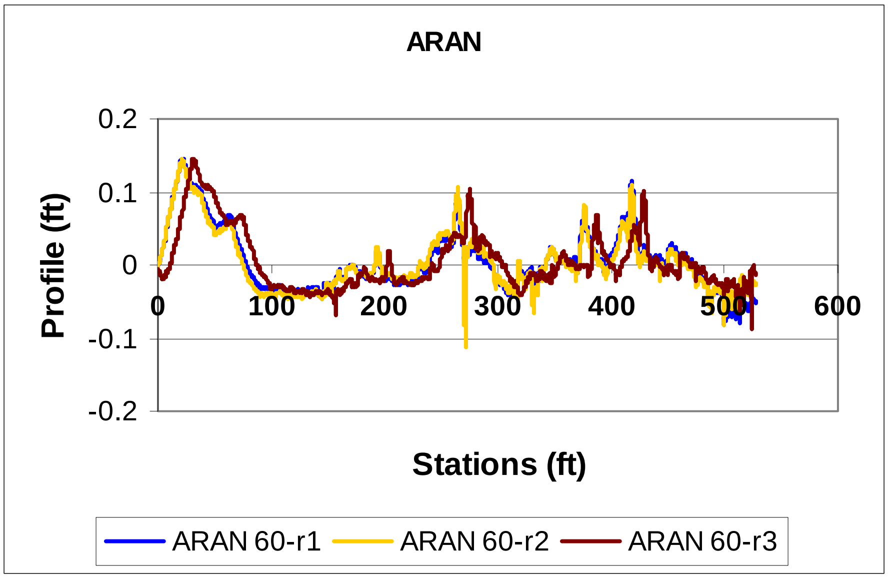


Figure B361: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

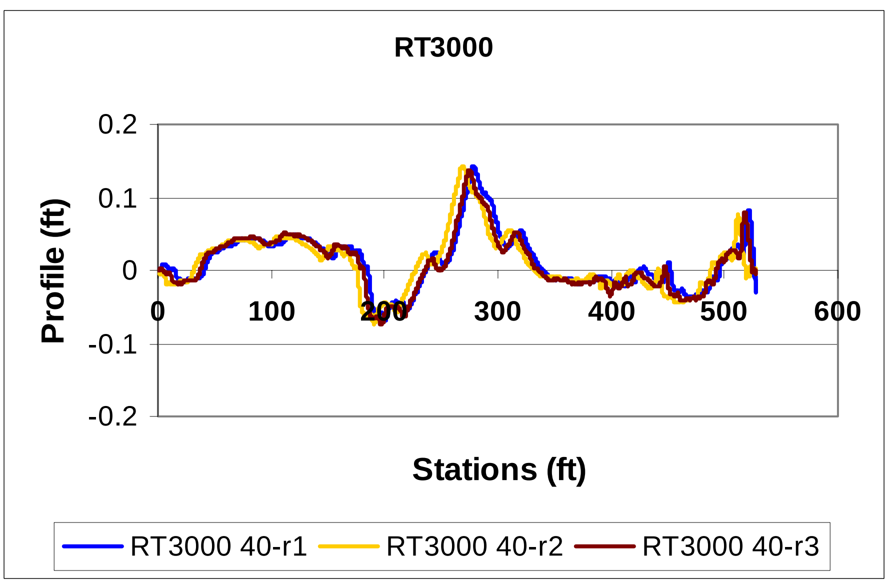


Figure B362: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

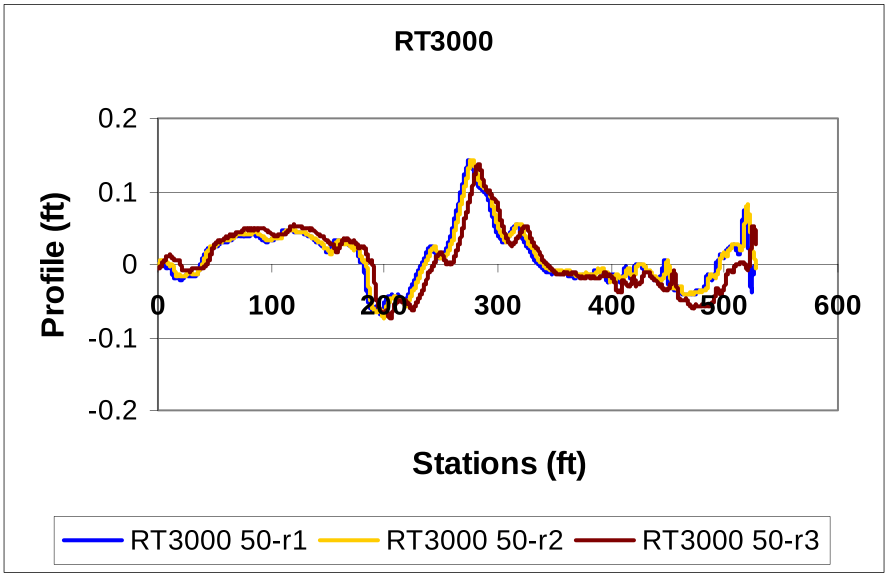


Figure B363: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

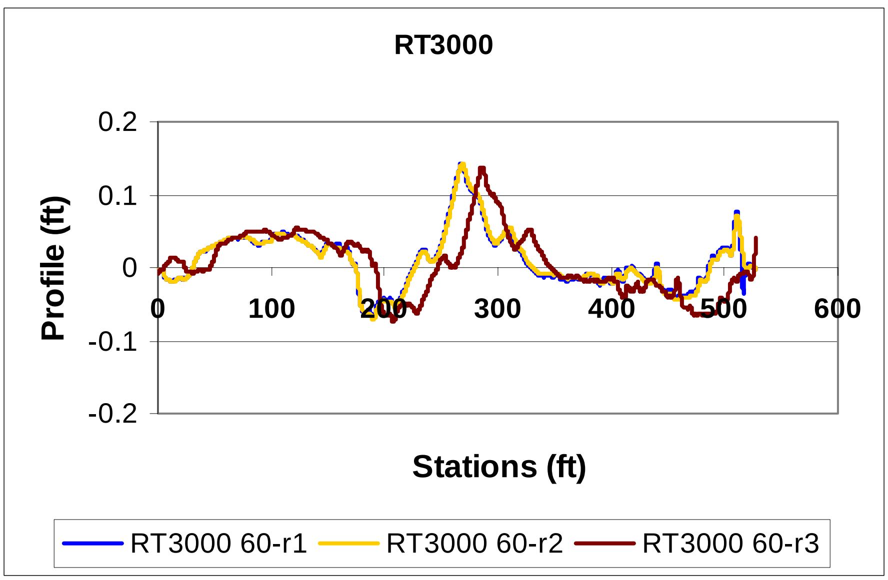


Figure B364: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

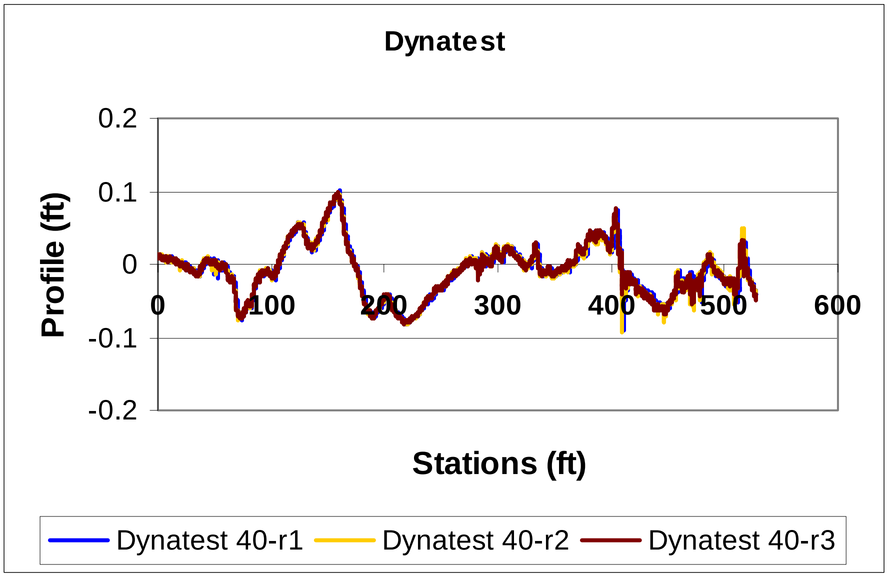


Figure B365: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

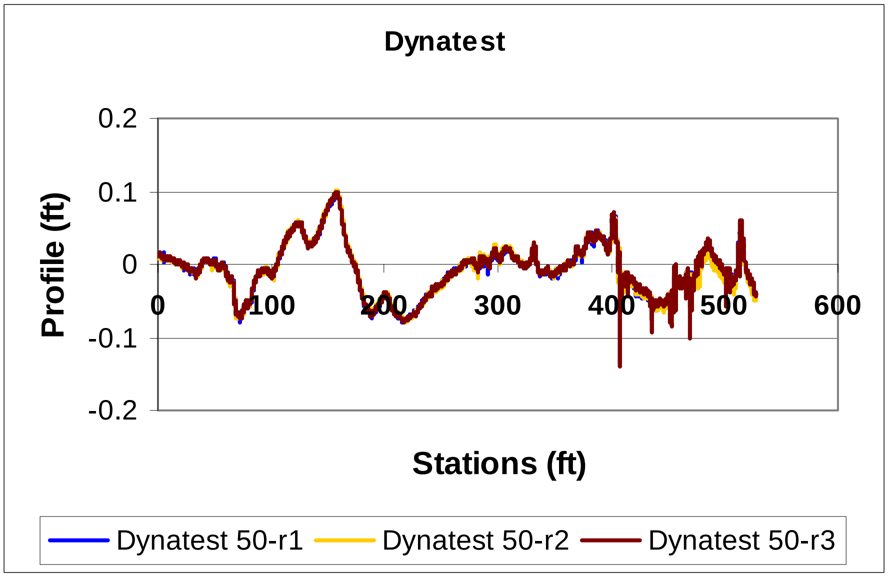


Figure B366: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

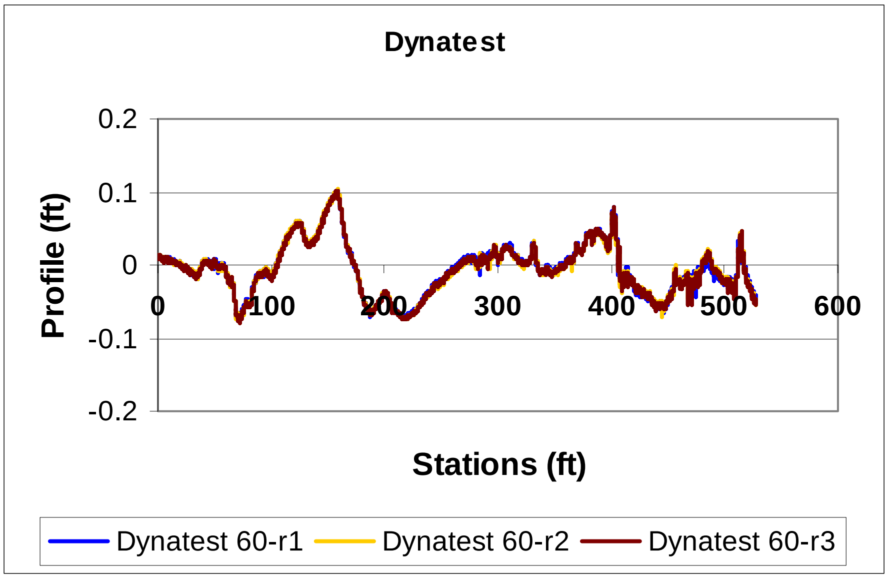


Figure B367: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

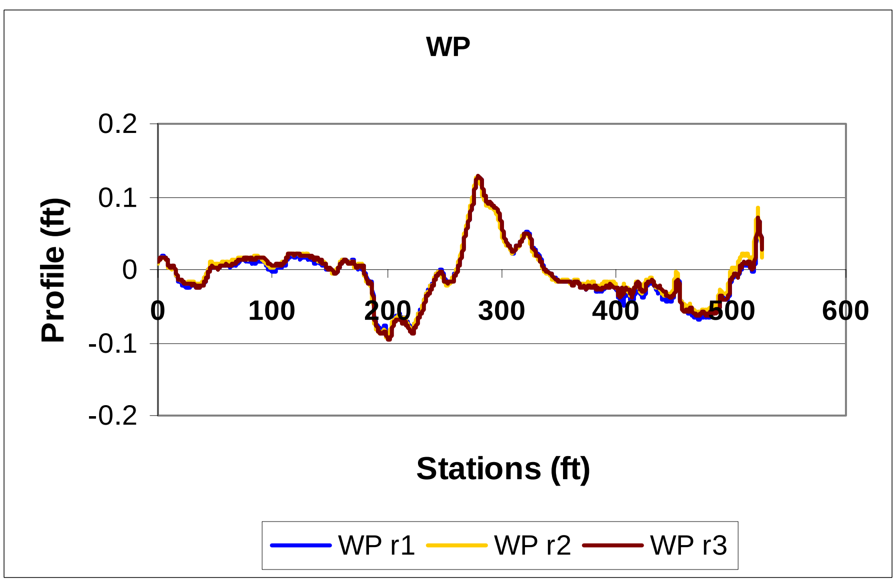


Figure B368: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

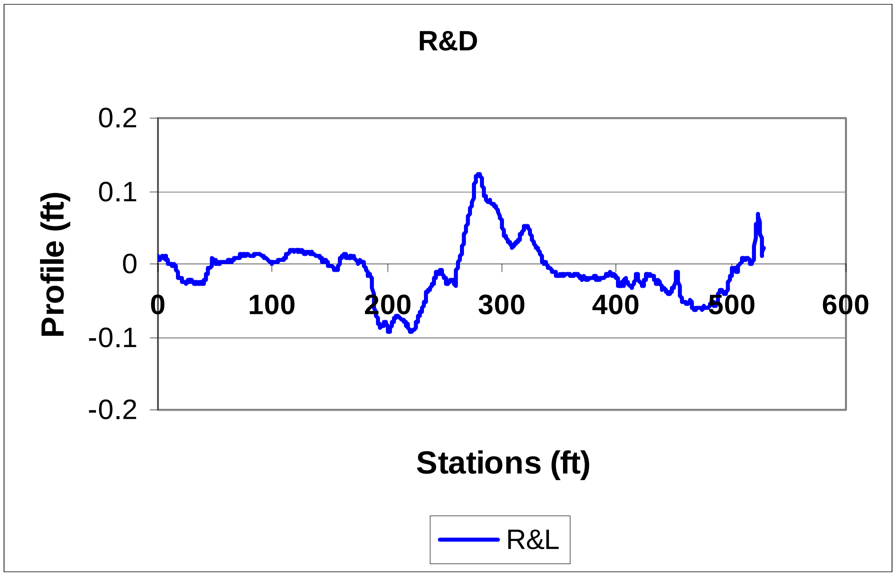


Figure B369: Profile, Route 18, Relatively Rough, Section 23, Right Wheel Path

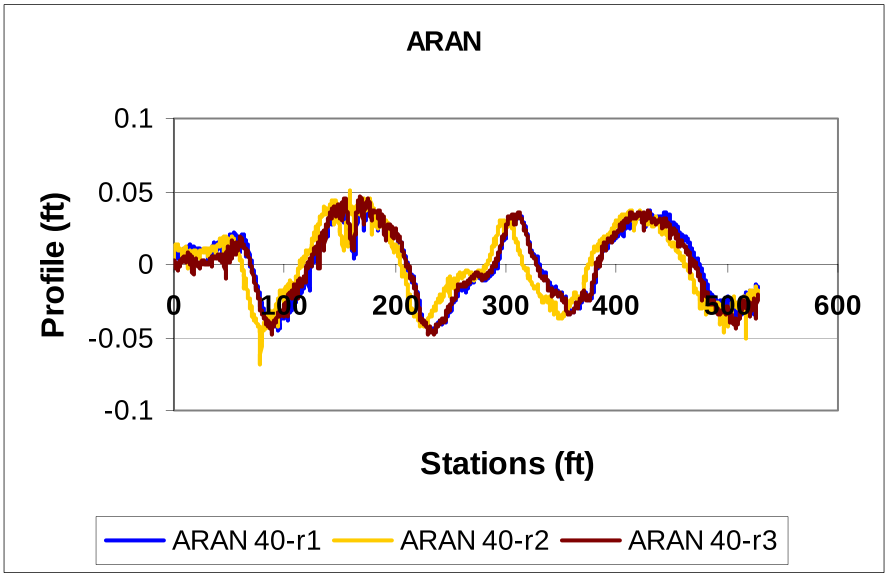


Figure B370: Profile, Route 195, Smooth, Section 1, Right Wheel Path

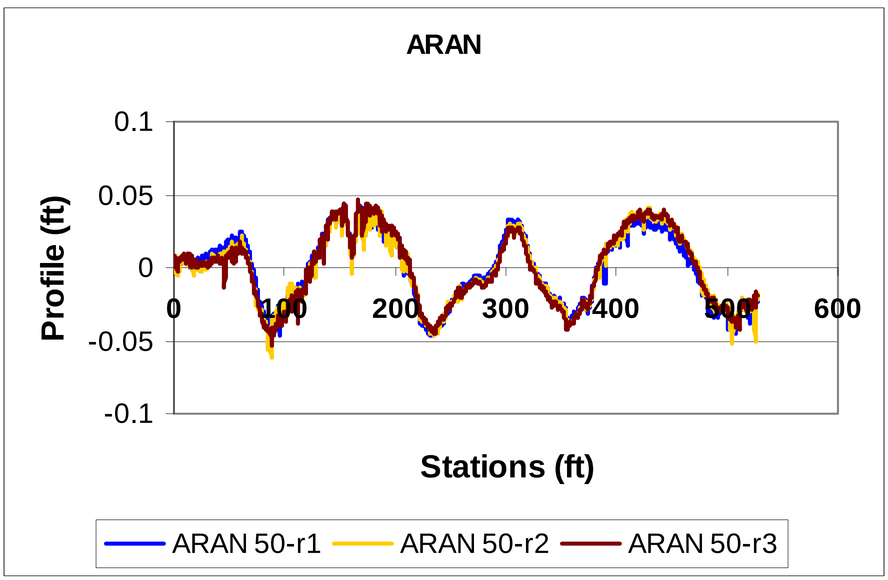


Figure B371: Profile, Route 195, Smooth, Section 1, Right Wheel Path

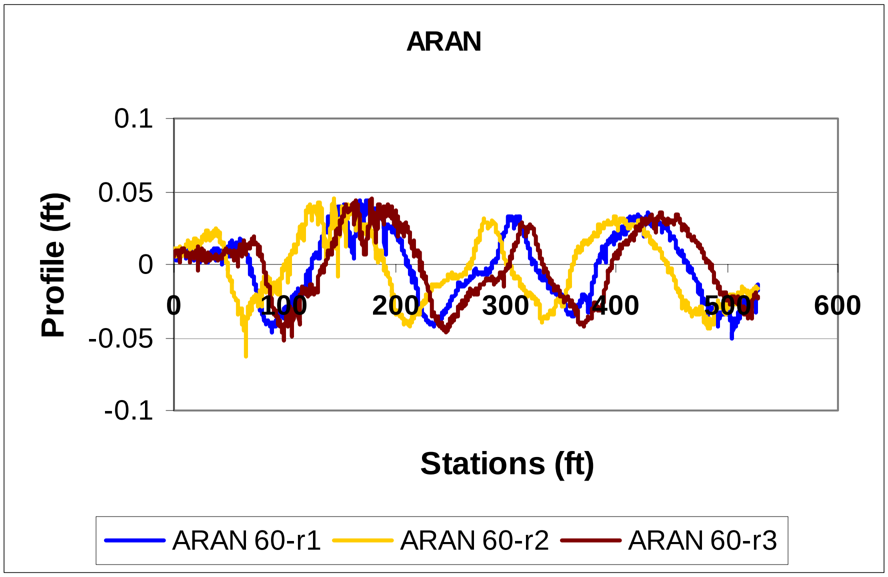


Figure B372: Profile, Route 195, Smooth, Section 1, Right Wheel Path

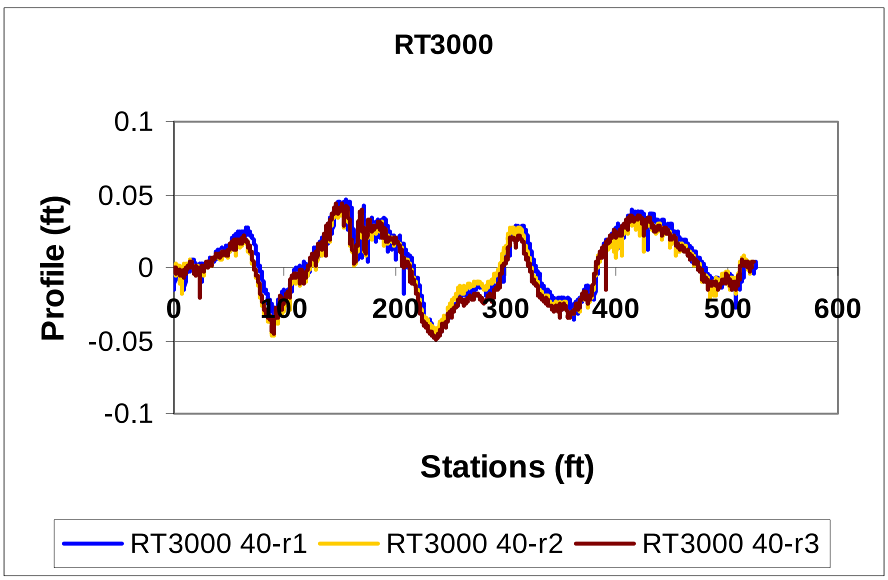


Figure B373: Profile, Route 195, Smooth, Section 1, Right Wheel Path

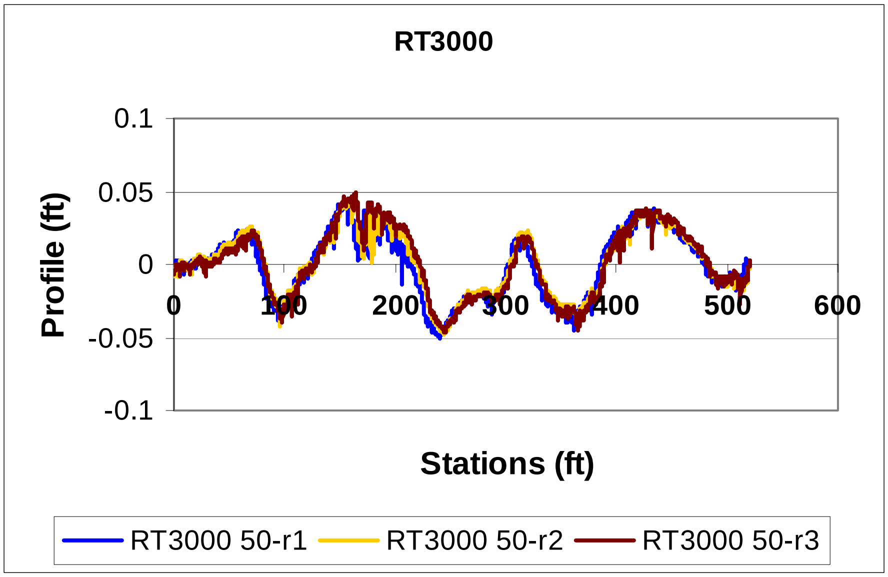


Figure B374: Profile, Route 195, Smooth, Section 1, Right Wheel Path

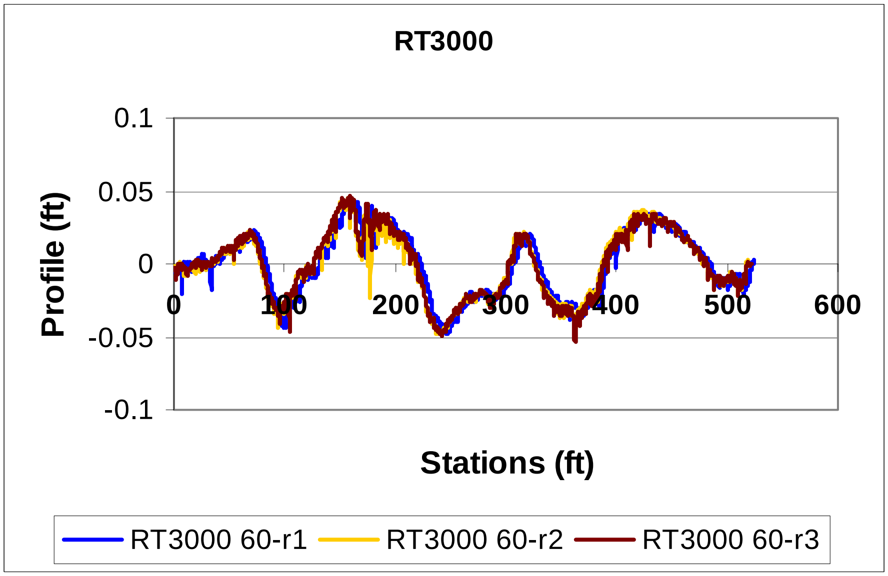


Figure B375: Profile, Route 195, Smooth, Section 1, Right Wheel Path

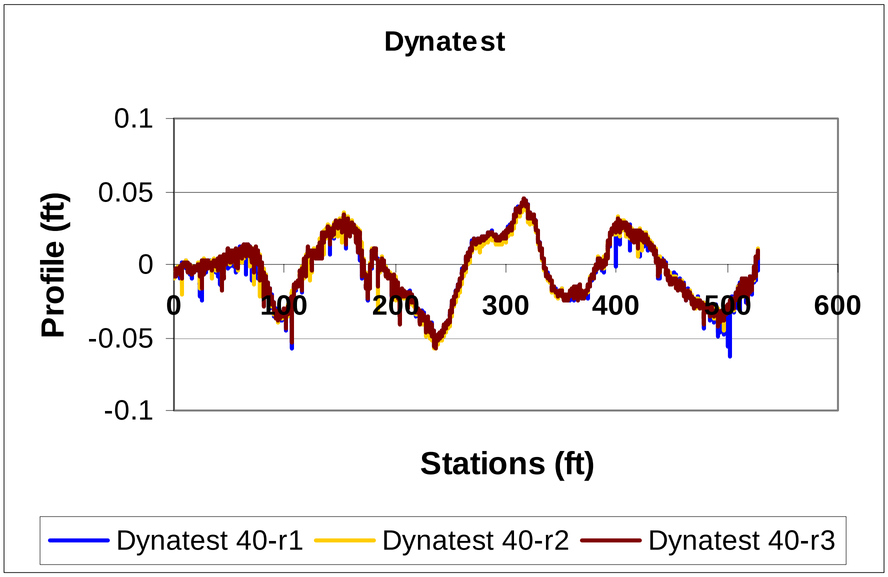


Figure B376: Profile, Route 195, Smooth, Section 1, Right Wheel Path

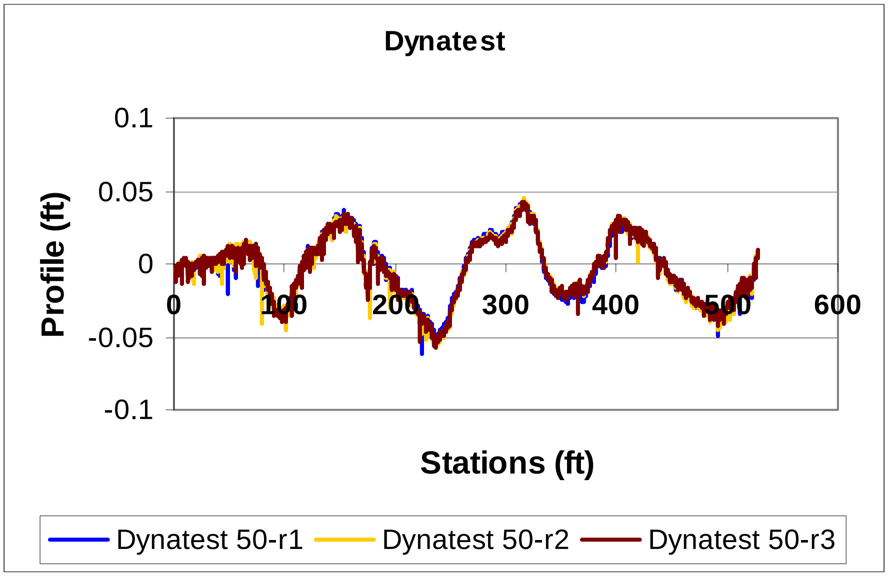


Figure B377: Profile, Route 195, Smooth, Section 1, Right Wheel Path

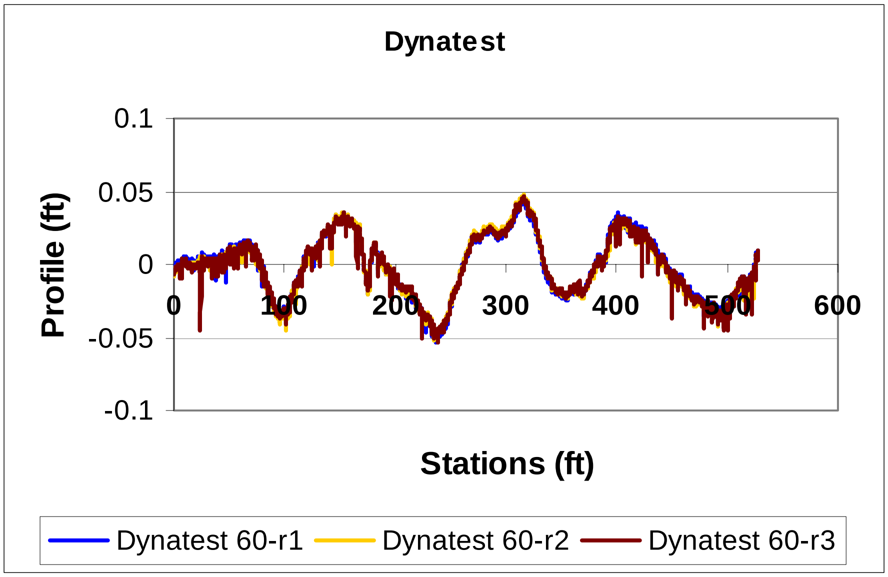


Figure B378: Profile, Route 195, Smooth, Section 1, Right Wheel Path

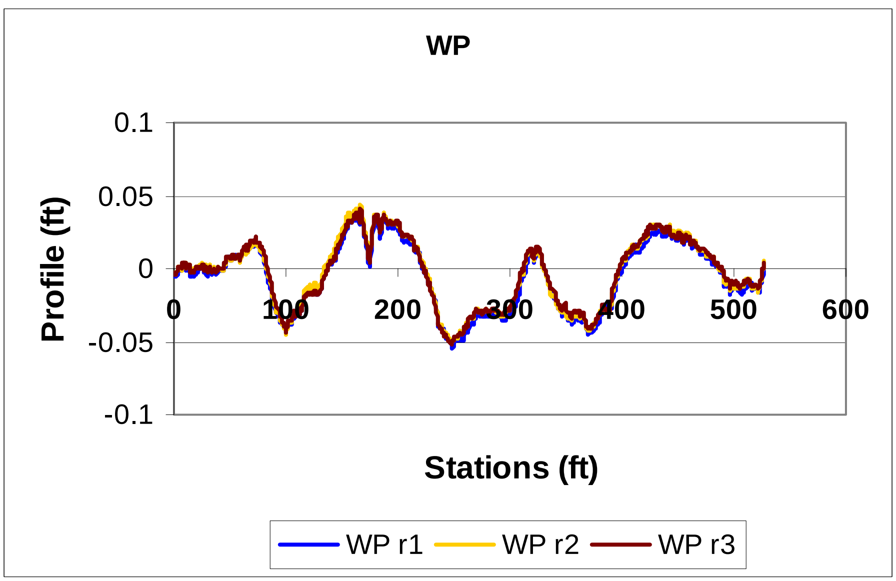


Figure B379: Profile, Route 195, Smooth, Section 1, Right Wheel Path

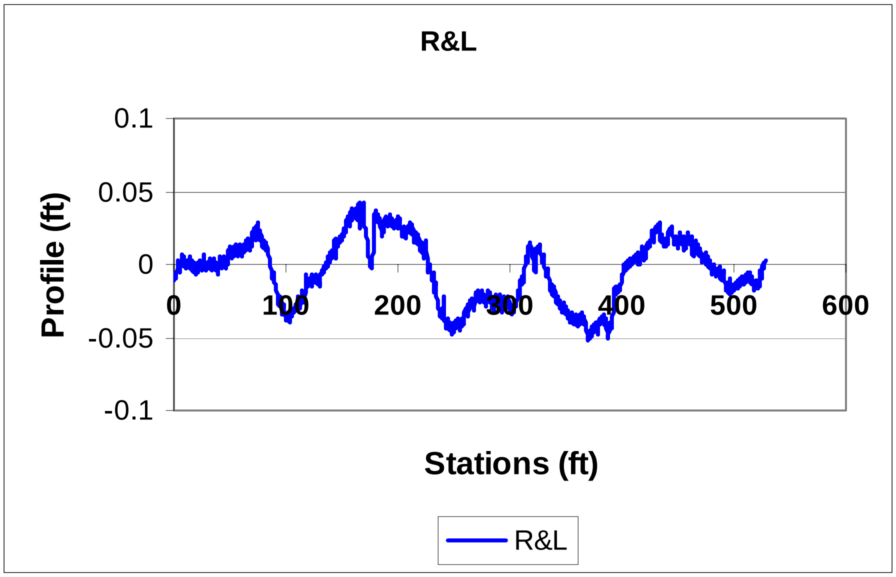


Figure B380: Profile, Route 195, Smooth, Section 1, Right Wheel Path

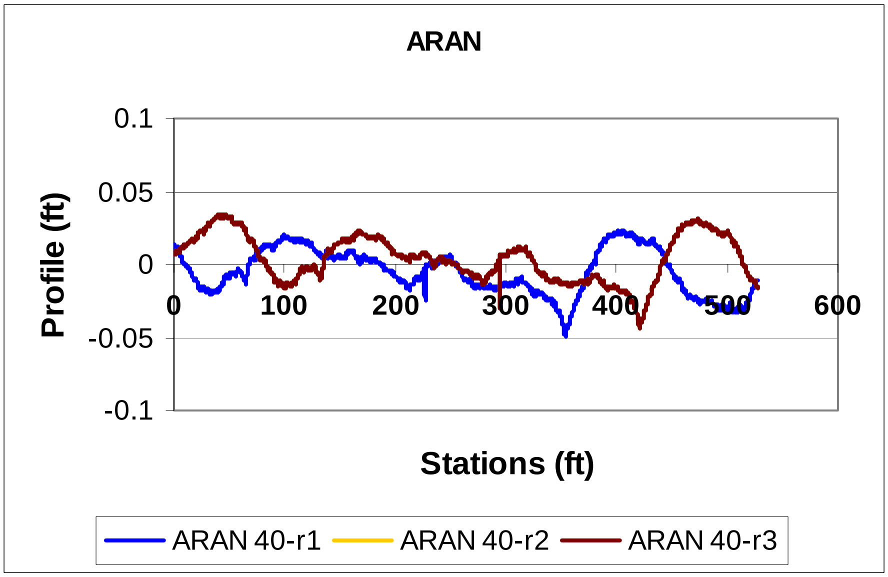


Figure B381: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

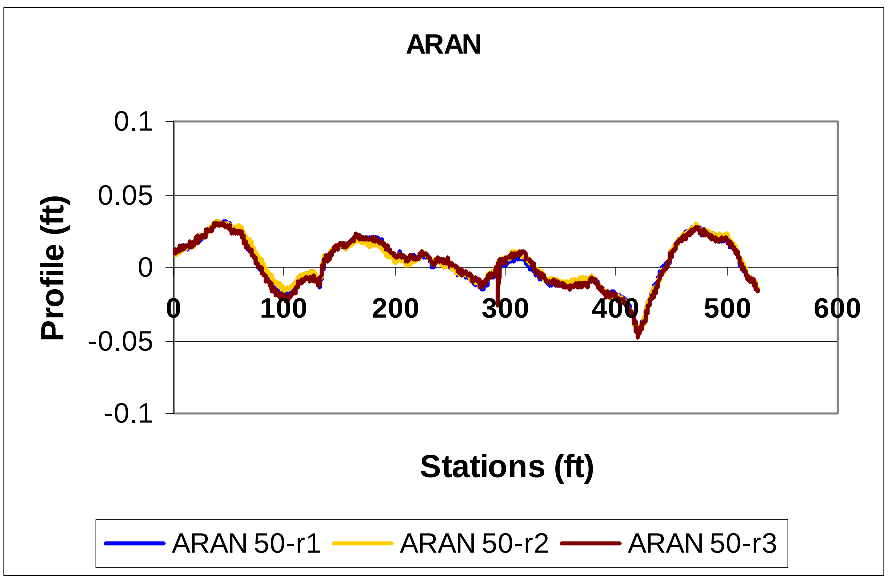


Figure B382: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

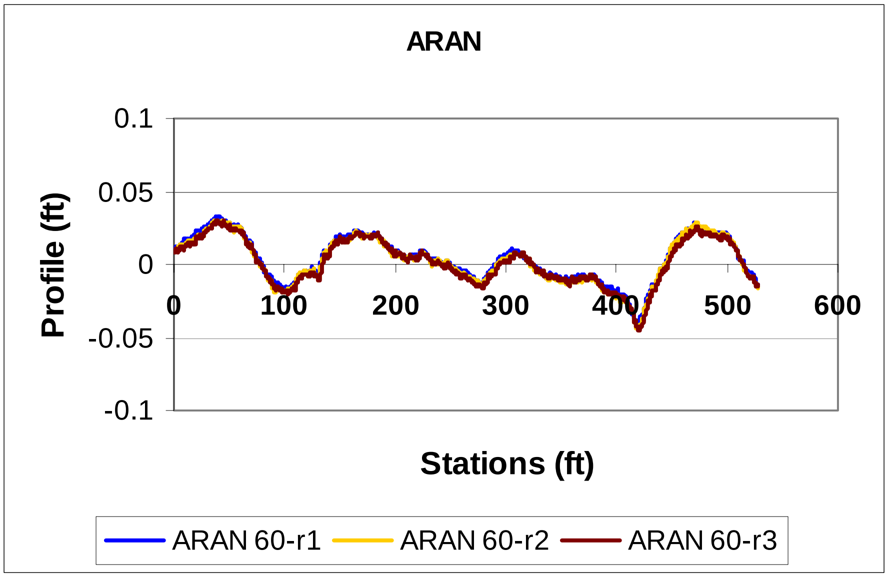


Figure B383: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

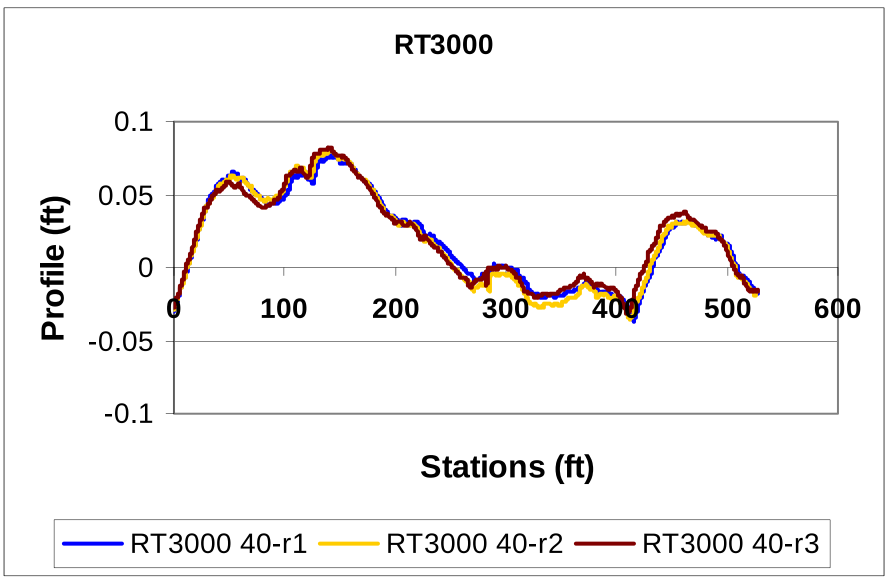


Figure B384: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

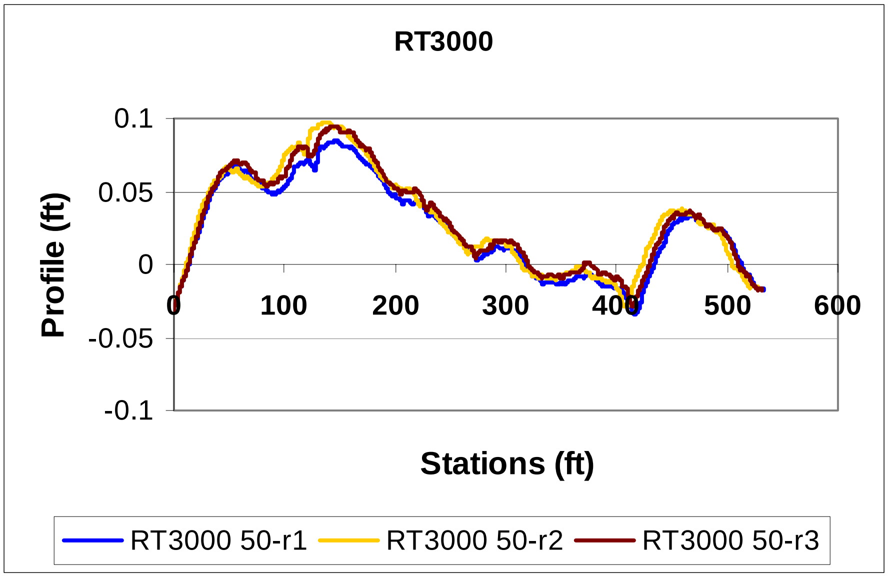


Figure B385: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

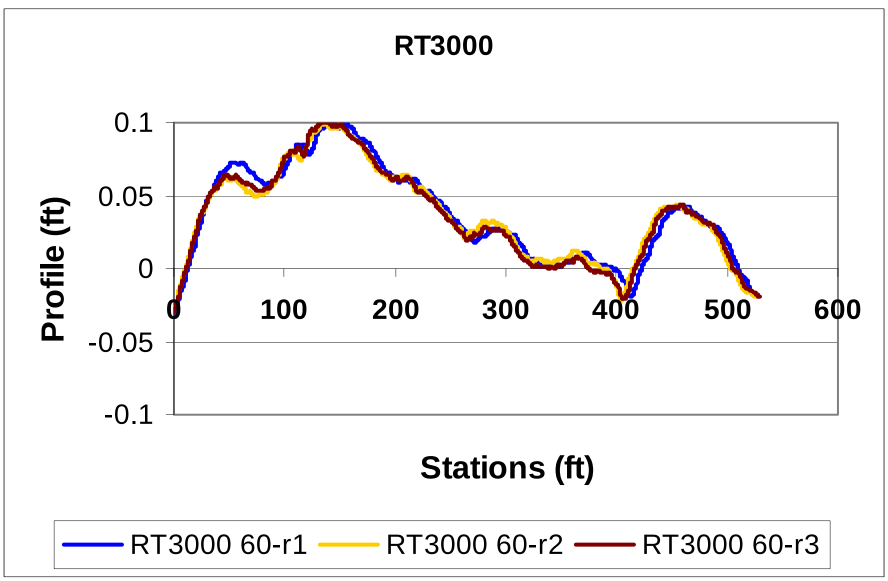


Figure B386: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

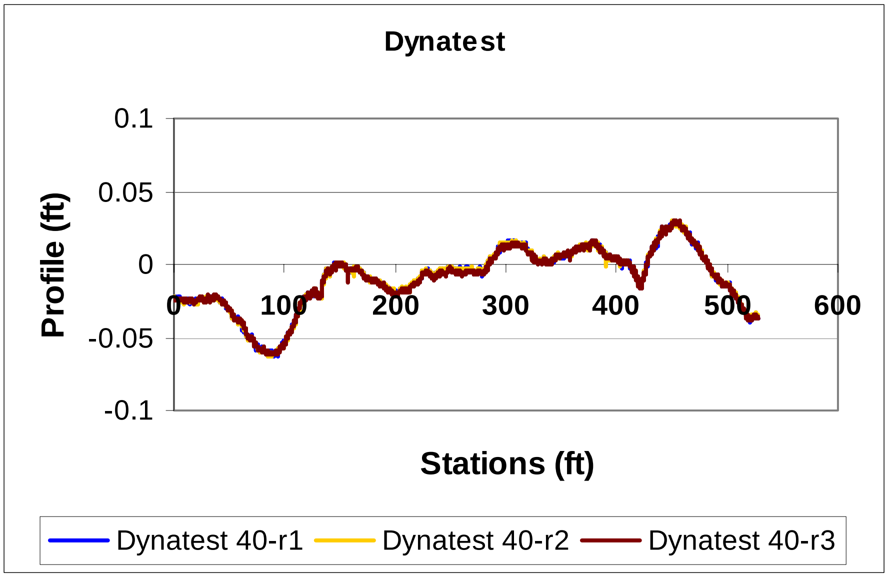


Figure B387: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

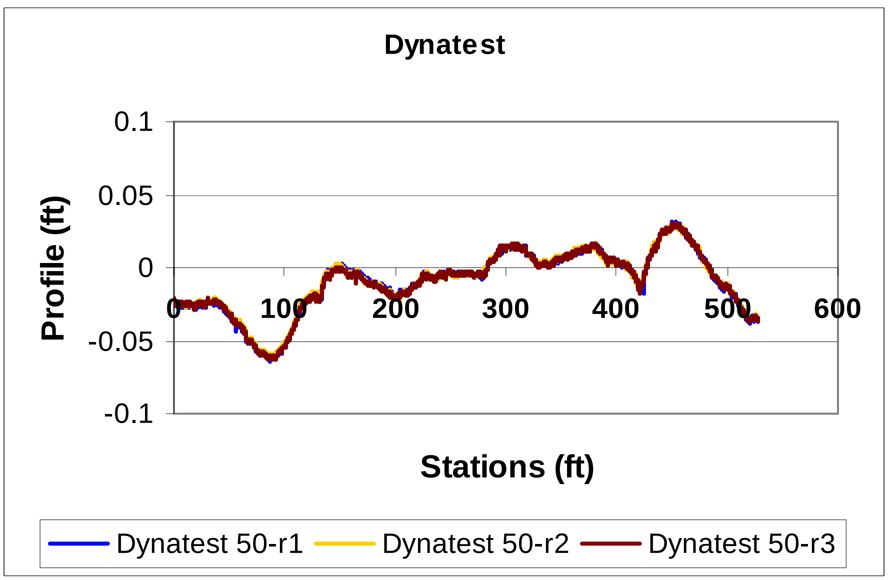


Figure B388: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

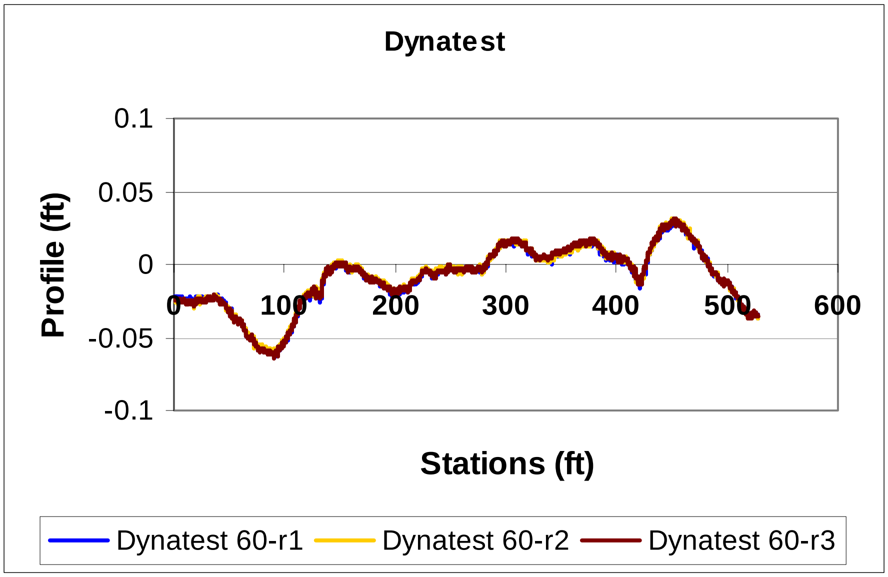


Figure B389: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

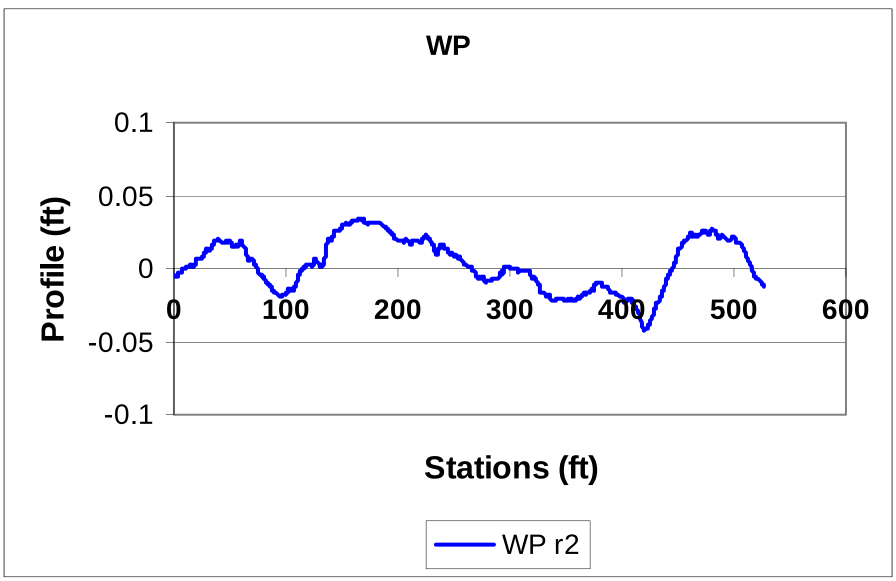


Figure B390: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

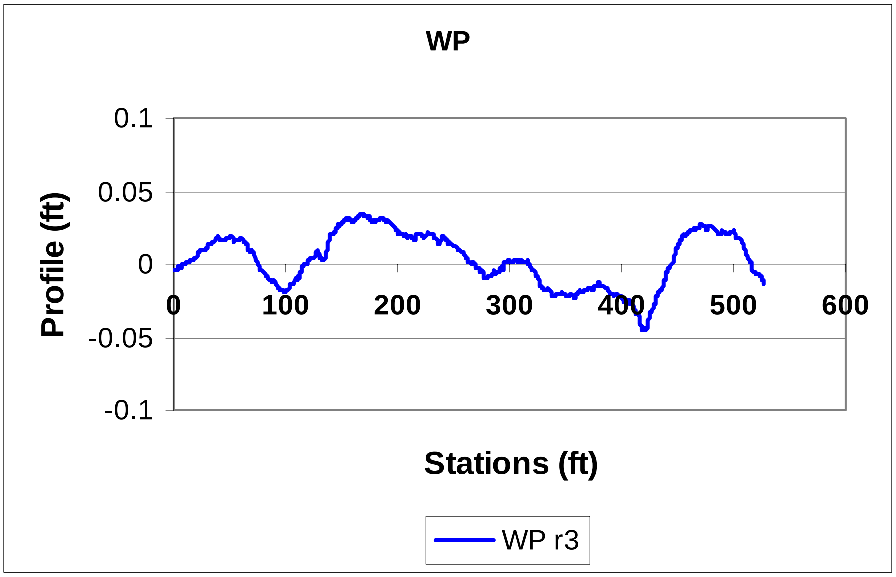


Figure B391: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

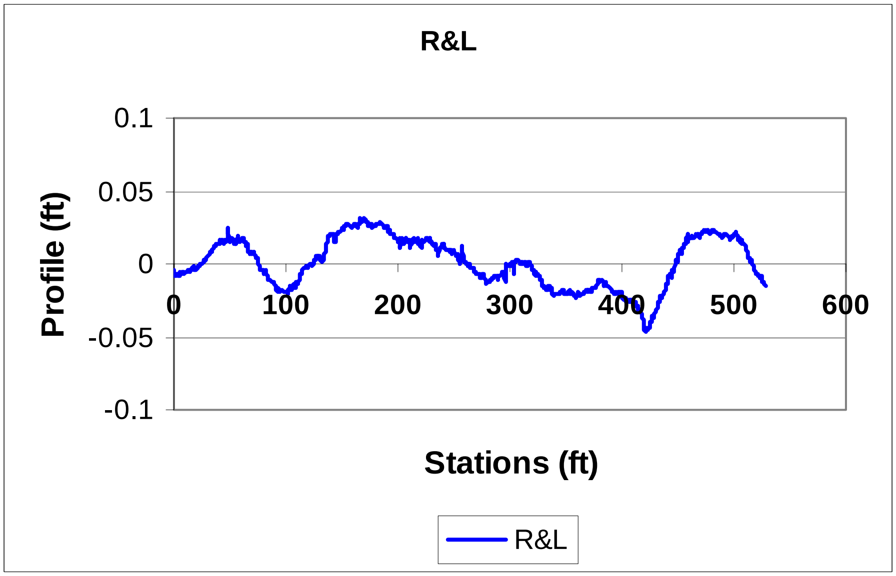


Figure B392: Profile, Route 55, Very Smooth, Section 11, Right Wheel Path

Table C1. IRI Runs - Route 55.

WALKING PROFILER CALCULATED WITH ROADRUF																								
DISTANCE [FT]																								
FROM	TO	S11L1	S11L2	S11L3	Average	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	38.68	52.13	55.36	48.72	37.05	33.1	35.08	34.25	33.7	28.45	32.13	51.84	58.41	55.17	55.14	37.79	38.9	37.08	37.92	54.48	55.68	52.66	54.27
52.8	105.6	45.58	52.97	52.42	50.32	54.8	53.64	54.22	41.5	47.86	49.96	46.44	55.86	48.14	55.01	53.00	38.47	47.6	38.16	41.41	43.65	45.83	42.47	43.98
105.6	158.4	46.37	51.8	54.74	50.97	87.54	76.68	82.11	31.16	28.79	31.94	30.63	42.58	37.66	44.47	41.57	38.6	31.7	32.44	34.25	42.6	49.36	38.33	43.43
158.4	211.2	42.82	40.68	46.92	43.47	30.28	37.71	34.00	50.42	59.89	65.15	58.49	67.77	67.29	66.88	67.31	37.77	33.38	35.88	35.68	46.74	41.37	45.32	44.48
211.2	264	51.32	55.79	45.96	51.02	62.08	53.36	57.72	42	41.62	41.38	41.67	56.48	53.32	54.94	54.91	71.62	62.76	58.15	64.18	61.28	62.03	66.55	63.29
264	316.8	30.84	33.91	35.07	33.27	45.71	52.55	49.13	35.11	29.42	26.6	30.38	48.36	52.43	45.42	48.74	49.78	50.33	37.91	46.01	68.19	60.59	57.13	61.97
316.8	369.6	37.58	40.33	42.26	40.06	47.55	55.52	51.54	51.76	57.53	52.7	54.00	43.45	46.51	44.66	44.87	42.53	47.27	47.09	45.63	35.64	40.19	37.92	37.92
369.6	422.4	47.07	52.1	41.98	47.05	57.12	46.42	51.77	51.99	51.26	43.89	49.05	38.22	36.25	39.29	37.92	62.02	57.93	60.56	60.17	56.28	64.64	64.63	61.85
422.4	475.2	70.59	58.93	67.22	65.58	75.61	70.61	73.11	41.55	42.69	56.18	46.81	64.83	59.21	65.71	63.25	43.43	40.84	40.7	41.66	55.79	49.43	53.72	52.98
475.2	528	38.2	44.82	46.43	43.15	66.83	62.35	64.59	48.81	48.18	49.62	48.87	82.85	81.04	77.42	80.44	45.83	40.44	44.78	43.68	47.21	46.31	43.07	45.53

40 MPH: ARAN IRI CALCULATED WITH ROADRUF																	
DISTANCE [FT]																	
FROM	TO	S11L1	Average	S11R1	Average	S12L1	S12L2	Average	S12R1	S12R2	Average	S13L1	S13L2	Average	S13R1	S13R2	Average
0	52.8	44.44	44.44	37.54	37.54	46.04	42.44	44.24	65.63	64.98	65.31	46.52	37.18	41.85	48.82	45.63	47.23
52.8	105.6	52.8	52.80	57.27	57.27	49.14	50.23	49.69	54.04	45.23	49.64	42.95	48.8	45.88	54.03	49.9	51.97
105.6	158.4	60.35	60.35	85.2	85.20	35.37	36.92	36.15	43.36	38.57	40.97	36.97	39.05	38.01	41.15	36.75	38.95
158.4	211.2	38.9	38.90	29.4	29.40	56.2	51.34	53.77	66.46	67.84	67.15	32.3	39.04	35.67	38.59	44.76	41.68
211.2	264	52.3	52.30	60.45	60.45	46.22	34.62	40.42	43.24	39.17	41.21	61.67	60.48	61.08	60.67	62.93	61.80
264	316.8	47.2	47.20	82.18	82.18	35.43	32.38	33.91	49.24	41.85	45.55	42.38	42.18	42.28	57.23	56.46	56.85
316.8	369.6	35.84	35.84	50.28	50.28	61.14	48.27	54.71	32.25	36.12	34.19	39.85	49.84	44.85	40.2	43.71	41.96
369.6	422.4	46.73	46.73	56.77	56.77	42.94	52.25	47.60	38.74	41.83	40.29	58.74	67.17	62.96	64.93	61.79	63.36
422.4	475.2	58.64	58.64	81.45	81.45	41.96	41.45	41.71	67.04	63.11	65.08	43.9	54.36	49.13	48.26	39.41	43.84
475.2	527.71	51.07	51.07	52.75	52.75	55.28	48.72	52.00	58.9	47.85	53.38	43.22	43.8	43.51	46.85	49.12	47.99

50 MPH: ARAN IRI CALCULATED WITH ROADRUF																								
DISTANCE [FT]																								
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	44.6	46.26	48.15	46.34	40.78	37.17	38.98	45.01	37.91	42.76	41.89	70.78	52.94	66.72	63.48	38.57	37.44	29.93	35.31	63.73	48.67	40.58	50.99
52.8	105.6	55.56	53.57	52.68	53.94	50.2	42.04	46.12	52.16	40.73	44.67	45.85	43.88	53.35	46.08	47.77	52.44	47.25	44.88	48.19	54.64	54.38	53.84	54.29
105.6	158.4	62.46	51.11	60.93	58.17	90.62	87.43	89.03	31.03	38.62	29.44	33.03	34.41	37.65	34.86	35.64	32.6	33.7	29.57	31.96	50.35	39.76	36.57	42.23
158.4	211.2	32.54	55.22	39.92	42.56	31.45	37.2	34.33	58.6	52.7	56.97	56.09	63.5	66.17	68.95	66.21	37.41	34.37	46.36	39.38	42.55	33.82	41.07	39.15
211.2	264	57.22	41.6	52.85	50.56	56.31	53.16	54.74	43.89	31.07	35.37	36.78	45.95	42.94	43.38	44.09	57.57	60.17	59.14	58.96	64.72	61.25	52.81	59.59
264	316.8	35.41	41.18	43.89	40.16	48.14	42.53	45.34	42.02	36.08	33.66	37.25	44.8	52.05	44.57	47.14	51.14	48.08	65.12	54.78	46.12	52.66	50.2	49.66
316.8	369.6	41.88	49.26	40.11	43.75	44.9	36.19	40.55	58.51	64.77	65	62.76	38.98	35.77	37.03	37.26	44.64	44.48	45.39	44.84	41.77	43.32	50.69	45.26
369.6	422.4	46.14	49.11	55.7	50.32	50.9	55.56	53.23	57.74	58.09	57.77	57.87	44.62	38.44	42.36	41.81	62	59.98	51.93	57.97	64.76	63.21	66.42	64.80
422.4	475.2	64.73	69.22	56.49	63.48	76.73	72.83	74.78	50.82	45.61	39.95	45.46	72.05	72.41	74.22	72.89	48.04	44.74	44.39	45.72	45.8	33.28	34.38	37.82
475.2	527.71	54.74	49.43	47.24	50.47	57.59	52	54.80	51.64	45.06	53.76	50.15	73.9	65.7	45.49	61.70	46.51	50.41	49.07	48.66	51.18	47.6	47.87	48.88

60 MPH: ARAN IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	45.98	43.92	48.95	46.28	29.79	45.85	46.52	40.72	49.97	46.03	56.61	50.87	67.96	57.23	62.82	62.67	35.81	42.66	33.25	37.24	39.53	38.83	42.08	40.15
52.8	105.6	60.56	60.76	38.41	53.24	44.45	51.2	46.73	47.46	52.67	50.62	64.61	55.97	47.53	60.11	60.55	56.06	56.35	69.01	41.89	55.75	52.82	47.49	48.78	49.70
105.6	158.4	58.31	63.79	51.33	57.81	83.94	91.31	82.19	85.81	52.42	31.7	38.68	40.93	37.79	53.68	42.5	44.66	36.99	31.07	42.33	36.80	44.8	35.79	42.8	41.13
158.4	211.2	71.48	50.46	51.96	57.97	34.55	35.73	37.05	35.78	60.51	63.67	62.34	62.17	73.08	81.63	70.83	75.18	40.99	42.54	54.78	46.10	31.27	41.38	37.53	36.73
211.2	264	48.74	68.07	33.52	50.11	55.48	53.48	55.03	54.66	59.11	39.17	41.48	46.59	49.75	54.21	55.29	53.08	63.95	62.34	70.86	65.72	61.47	61.49	61.84	61.60
264	316.8	47.12	47.84	55.85	50.27	44.96	45.18	49.54	46.56	49.55	44.66	50.39	48.20	42.3	55.61	48.53	48.81	52.07	57.57	60.71	56.78	54.95	53.94	47.29	52.06
316.8	369.6	46.55	37.68	64.6	49.61	45.17	43.76	46.89	45.27	64.82	53.61	66.94	61.79	37.14	48.89	47.19	44.41	53.4	49.87	55.81	53.03	46.58	55.2	50.63	50.80
369.6	422.4	60.78	68.03	59.38	62.73	62.58	54.88	50.17	55.88	61.04	60.72	52.31	58.02	46.4	40.57	49.86	45.61	59.26	63.02	58.26	60.18	63.05	64.9	68.21	65.39
422.4	475.2	80.51	65.48	71.22	72.40	75.67	73.62	75.6	74.96	51.54	66.51	60.79	59.61	77.47	73.38	78.87	76.57	43.75	52.09	40.71	45.52	40.01	38.55	38.29	38.95
475.2	527.71	59.63	46.74	56.14	54.17	60.74	53.28	49.73	54.58	54.69	64.76	59.9	59.78	46.54	80.41	60.71	62.55	49.75	47.67	47.56	48.33	51.83	53.82	50.32	51.99

40 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	47.29	44.73	44.22	45.41	39.9	36.33	40.1	38.78	37.92	39.84	34.55	37.44	46.34	49.39	64.41	53.38	28.17	34.75	30.86	31.26	34.03	41.63	41.15	38.94
52.8	105.6	44.95	43.53	49.83	46.10	43.04	44.48	47.73	45.08	42.7	37.9	42.79	41.13	50.9	47.55	45.38	47.94	43.41	46.14	43.5	44.35	46.34	49.65	52.15	49.38
105.6	158.4	53.58	59.01	56.24	56.28	84.18	76.81	78.47	79.82	26.1	25.25	26.42	25.92	51.37	45.3	40.5	45.72	24.51	24.46	25.35	24.77	28.78	33.88	30.76	31.14
158.4	211.2	29.78	32.37	37.66	33.27	34.17	35.47	33.39	34.34	67.18	69.22	63.77	66.72	68.74	71.11	67.49	69.11	43.41	44.19	44.57	44.06	43.31	43.26	44.09	43.55
211.2	264	42.6	42.37	41.34	42.10	47.47	46.22	47.67	47.12	36.86	40.39	32.9	36.72	51.67	66.43	53.27	57.12	53.49	56.52	52.62	54.21	60.39	62.51	59.88	60.93
264	316.8	38.77	36.41	37.1	37.43	53.53	73.11	71.3	65.98	34.43	54.4	42.12	43.65	39.22	59.92	41.54	46.89	45.48	46.39	46.81	46.23	50.22	43.42	46.43	46.69
316.8	369.6	31.7	34.14	35.51	33.78	40.63	53.41	49.3	47.78	50.27	37.83	47.14	45.08	44.71	49.54	36.86	43.70	44.04	46.73	44.25	45.01	35.4	41.19	43.58	40.06
369.6	422.4	59.94	56.1	63.26	59.77	65.18	73.79	65.92	68.30	39.85	50.01	49.98	46.61	39.09	47.23	41.34	42.55	62.15	57.52	55.59	58.42	64.87	56.43	55.74	59.01
422.4	475.2	51.41	51.2	46.47	49.69	59.71	60.24	60.95	60.30	45.86	51.96	44	47.27	64.23	66.38	66.95	65.85	34.08	32.33	32.56	32.99	43.77	36.53	35.65	38.65
475.2	527.71	54.02	54.99	48.44	52.48	51.7	51.07	53.31	52.03	45.89	52.11	49.21	49.07	78.33	86.11	73.76	79.40	41.71	37.37	41.57	40.22	50.33	50.29	46.77	49.13

50 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	40.49	55.01	61	52.17	32.94	48.38	31.03	37.45	39.73	48.83	40.84	43.13	60.24	52.66	55.31	56.07	27.12	34.2	31.65	30.99	36.58	36.18	37.51	36.76
52.8	105.6	49.7	49.89	42.98	47.52	39.28	49.97	50.4	46.55	45.23	39.71	37.08	40.67	45.15	44.61	43.37	44.38	51.95	49.33	48.14	49.81	54.27	50.42	51.98	52.22
105.6	158.4	53.38	51.22	54.37	52.99	83.66	73.6	72.52	76.59	22.24	32.2	27.02	27.15	32.04	43.44	40.91	38.80	35.97	29.77	26.19	30.64	24.91	28.1	30.84	27.95
158.4	211.2	36.3	42.3	37.12	38.57	32.44	35.26	43.27	36.99	53.76	65.38	67.33	62.16	67.28	69.88	70.8	69.32	42.61	41.46	46.8	43.62	41.52	46.72	43.61	43.95
211.2	264	54.86	36.18	55.34	48.79	50.31	43.09	53.43	48.94	33.7	35.73	37.41	35.61	41.72	53.41	44.49	46.54	55.53	59.19	54.55	56.42	46.45	49.75	64.48	53.56
264	316.8	40.17	43.27	37.7	40.38	48.1	55.02	58.21	53.78	38.07	41.81	39.95	39.94	39.05	49.03	44.48	44.19	55.45	52.15	42.08	49.89	51.44	50.53	44.21	48.73
316.8	369.6	40.45	35.29	42.63	39.46	40.82	46.65	45.38	44.28	40.81	47.4	47.83	45.35	34.95	40.12	38.81	37.96	39.57	47.01	44.63	43.74	41.46	45.47	39.74	42.22
369.6	422.4	67.39	58.64	56.79	60.94	60.4	62.71	79.66	67.59	50.95	50.82	48.16	49.98	37.2	47.48	44.01	42.90	55.08	53.71	61.91	56.90	57.96	58.54	59.46	58.65
422.4	475.2	57.49	50.65	50.97	53.04	64.9	59.74	62.43	62.36	43	51.96	51.75	48.90	66.69	68.47	62.87	66.01	39.71	32.65	40.11	37.49	32.98	37.7	33.65	34.78
475.2	527.71	49.74	56.07	51.14	52.32	54.05	60.56	51.97	55.53	55.4	50.26	45.12	50.26	76.26	78.52	84.71	79.83	41.06	43.8	40.57	41.81	48.26	50.88	53.07	50.74

60 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																								
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	54.01	58.08	51.24	54.44	39.09	42.72	46.62	42.81	36.64	47.44	47.36	43.81	57.73	58.07	57.90	31.39	33.91	32.89	32.73	30.18	47.21	34.94	37.44
52.8	105.6	42.16	50.38	48.6	47.05	45.36	55.58	47.57	49.50	40.71	46.82	41.74	43.09	42.04	43.37	42.71	44.58	51.91	56.75	51.08	44.11	58.25	52.48	51.61
105.6	158.4	55.15	49.78	46.39	50.44	75.06	70.03	78.15	74.41	22.91	31.81	29.46	28.06	39.68	40.77	40.23	30.78	26.84	26.69	28.10	29.82	48.51	28.26	35.53
158.4	211.2	33.2	39.56	41.92	38.23	39.1	43.09	36.68	39.62	65.01	58.1	59.48	60.86	69.52	72.19	70.86	49.66	41.6	46.12	45.79	47.61	47.78	42.72	46.04
211.2	264	45.59	45.05	34.38	41.67	46.64	62.71	47.35	52.23	34.8	34.78	30.13	33.24	39.67	38.37	39.02	63.09	56.77	54.9	58.25	59.59	61.99	55.16	58.91
264	316.8	37.47	39.68	41.27	39.47	51.28	62.05	48.97	54.10	34.17	43.18	41.8	39.72	46.11	44.05	45.08	52.98	57.23	63.47	57.89	43.84	54.39	47.99	48.74
316.8	369.6	45.55	38.41	38.24	40.73	41.1	47.96	47.29	45.45	47.88	33.91	44.07	41.95	34.72	38.61	36.67	42.4	48.42	52.16	47.66	46.76	48.74	47.16	47.55
369.6	422.4	73.7	57.64	58.1	63.15	66.02	66.78	62.93	65.24	52.23	46.82	56.66	51.90	39.64	51.09	45.37	56.21	53.2	59.55	56.32	53.99	56.63	50.78	53.80
422.4	475.2	50.77	51.33	46.63	49.58	57.7	62.21	63.19	61.03	51.29	48.6	48.08	49.32	68.52	72.43	70.48	36.45	39.29	40.34	38.69	41.83	38.15	35.24	38.41
475.2	527.71	52.2	58.11	45.82	52.04	47.21	49.13	47.88	48.07	51.04	51.02	52.98	51.68	76.99	82.94	79.97	41.59	44.31	41.85	42.58	49.55	55.13	49.46	51.38

40 MPH: Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	40.1	40.96	41.31	40.79	33.46	32.83	32.81	33.03	46.25	38.56	42.79	42.53	58.02	63.11	65.66	62.26	45.4	42.76	45.39	44.52	51.97	52.44	50.38	51.60
52.8	105.6	50.17	49.8	51.43	50.47	41.97	41.79	42.5	42.09	40.75	41.5	38.06	40.10	48.69	51.46	50.78	50.31	46.6	45.88	47.61	46.70	48.81	55.15	48.42	50.79
105.6	158.4	57.03	57.47	56.4	56.97	79.22	78.97	77.14	78.44	29.22	30.44	28.41	29.36	45.95	45.91	44.82	45.56	36.81	37.7	37.22	37.24	40.55	40.48	38.06	39.70
158.4	211.2	35.79	34.49	37.97	36.08	30.54	31.19	30.87	30.87	61.54	59.85	60.16	60.52	68.04	66.55	64.32	66.30	36.55	33.06	31.24	33.62	38.8	36.15	40.4	38.45
211.2	264	47.15	49.04	46.74	47.64	53.56	53.57	51.13	52.75	39.63	40.54	37.67	39.28	49.26	53.82	54.03	52.37	52.25	48.34	50.83	50.47	61.23	62.42	61.08	61.58
264	316.8	36.91	35.3	33.78	35.33	47.05	46.47	46.1	46.54	40.3	42.31	40.02	40.88	43.28	43.05	47.2	44.51	41.43	43.72	43	42.72	56.44	50.92	53.55	53.64
316.8	369.6	37.9	39.32	41.25	39.49	48.11	49.34	47.21	48.22	51.18	51.39	48.92	50.50	42.93	47.95	43.5	44.79	52.49	51.36	51.3	51.72	37.13	35.98	36.25	36.45
369.6	422.4	45.88	43.36	44.26	44.50	43.64	45.54	47.14	45.44	36.92	52.16	39.63	42.90	41.1	39.6	43.1	41.27	63.28	61.35	61.26	61.96	62.23	62.18	63.73	62.71
422.4	475.2	54.63	56.62	57.33	56.19	77.92	81.07	79.13	79.37	37.16	48.72	38.39	41.42	64.69	69.63	66.57	66.96	37.03	38.69	34.82	36.85	42.99	43.1	49.33	45.14
475.2	527.71	52.07	51.37	51.69	51.71	54.7	52.52	52.41	53.21	60.44	64.49	55.66	60.20	85.4	81.29	82.49	83.06	44.15	43.45	41.94	43.18	46.75	45.61	50.21	47.52

50 MPH: Dynatest IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	45.25	42.97	44.03	44.08	35.29	31.97	33.99	33.75	44.9	32.19	39.36	38.82	57.17	61.96	62.08	60.40	40.24	46.13	44.21	43.53	44.38	47.55	45.48	45.80
52.8	105.6	51.54	49.28	50.08	50.30	41.29	37.95	38.98	39.41	37.74	43.11	39.48	40.11	53.36	47.61	51.49	50.82	39.75	37.17	42.08	39.67	41.51	44.54	45.82	43.96
105.6	158.4	59.83	51.21	53.81	54.95	83.02	76.88	76.07	78.66	30.56	30.84	26.83	29.41	42.27	42.84	42.87	42.66	33.5	33.22	33.14	33.29	37.26	36.25	39.38	37.63
158.4	211.2	36.61	39.63	34.21	36.82	32	32.1	32.94	32.35	59.34	56.63	64.44	60.14	68.17	66.53	66.3	67.00	33.27	35.77	34.08	34.37	32.79	31.84	34.82	33.15
211.2	264	45.29	46.8	46.06	46.05	51.09	47.1	50.38	49.52	40.96	40.14	42.45	41.18	48.86	46.82	51.57	49.08	56.03	57.39	54.57	56.00	58.14	55.96	59.57	57.89
264	316.8	34.89	37.77	33.44	35.37	47.22	44.5	45.98	45.90	37.68	34.11	37.34	36.38	45.83	45.21	41.66	44.23	40.59	49.14	41.56	43.76	51.98	52.67	55.65	53.43
316.8	369.6	37.71	39.61	38.26	38.53	49.8	41.53	47.61	46.31	56.97	58.95	57.11	57.68	38.03	34.46	38.81	37.10	48.63	47.27	49.49	48.46	37.96	40.5	36.47	38.31
369.6	422.4	45.13	42.77	44.91	44.27	47.53	44.76	45.11	45.80	52.27	48.19	49.5	49.99	39.4	36.77	38.45	38.21	60.18	59.57	64.91	61.55	65.37	64.88	63.88	64.71
422.4	475.2	56.35	59.86	54.04	56.75	79.24	77.34	76.77	77.78	41.84	41.14	39.59	40.86	63.43	63.79	63.47	63.56	40.43	43.27	35.83	39.84	41.23	39.06	45.88	42.06
475.2	527.71	52.73	48.69	49.96	50.46	55.76	54.08	52.98	54.27	50.83	51.33	51.21	51.12	76.33	77.75	72.2	75.43	42.76	42.99	43.32	43.02	44.4	46.12	47.77	46.10

60 MPH: Dynatest IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S11L1	S11L2	S11L3	Average	S11R1	S11R2	S11R3	Average	S12L1	S12L2	S12L3	Average	S12R1	S12R2	S12R3	Average	S13L1	S13L2	S13L3	Average	S13R1	S13R2	S13R3	Average
0	52.8	43.83	42.49	42.34	42.89	33.73	35.44	30.84	33.34	38.07	40.86	37.33	38.75	64.69	67.13	62.64	64.82	40.23	40.16	40.91	40.43	40.14	40.74	42.86	41.25
52.8	105.6	49.5	44.69	48.34	47.51	40.44	35.38	40.48	38.77	40.89	38.85	39.04	39.59	52.63	51.36	53.2	52.40	39.87	41.33	43.41	41.54	42.4	43.31	45.03	43.58
105.6	158.4	60.12	53.92	58.1	57.38	81.53	75.97	78.18	78.56	31.78	30.49	31.57	31.28	44.13	44.27	41.1	43.17	32.92	33.73	34.21	33.62	36.15	36.64	37.02	36.60
158.4	211.2	34.95	35.74	40.18	36.96	31.34	33.19	29.01	31.18	60.32	59.73	63.22	61.09	67.53	66.85	64.43	66.27	36.63	36.97	31.71	35.10	32.7	31.56	32.39	32.22
211.2	264	50.69	48.82	45.18	48.23	55.9	54.56	51.34	53.93	38.06	39.49	40.33	39.29	48.88	50.83	53.04	50.92	54.94	55.41	52.47	54.27	55.34	57.64	63.86	58.95
264	316.8	35.62	33.87	37.65	35.71	43.29	46.4	47.51	45.73	32.33	34.32	41.27	35.97	43.59	42.63	43.46	43.23	48.01	42.43	42.76	44.40	51.96	51.47	54.26	52.56
316.8	369.6	43.43	40.9	43	42.44	46.11	48.11	42.77	45.66	54.23	55.54	61.12	56.96	37.54	35.84	39.18	37.52	45.4	49.6	51.38	48.79	40.09	36.84	37.28	38.07
369.6	422.4	41.24	47.14	42.59	43.66	46.62	43.65	46.4	45.56	49.44	48.98	48.19	48.87	34.61	36.83	36.15	35.86	59.94	61.65	63.8	61.80	63.94	61.16	62.56	62.55
422.4	475.2	61.58	56.86	61.15	59.86	79.85	79.24	77.03	78.71	43.14	42.53	40.96	42.21	60.72	62.23	66.69	63.21	38.35	34.74	37.63	36.91	40.23	43.3	45.94	43.16
475.2	527.71	50.73	51.06	50.71	50.83	54.11	57.17	56.44	55.91	48.33	47.19	47.3	47.61	67.61	68.65	70.5	68.92	42.44	43.36	42.73	42.84	43	44.6	45.94	44.51

Table C2. IRI Runs - Route 195.

WALKING PROFILER CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	65.82	60.98	54.78	60.53	55.75	52.28	54.5	54.18	65.08	65.04	67.35	65.82	73.64	71.34	81.24	75.41	92.37	89.12	91.15	90.88	113.43	121.15	105.87	113.48
52.8	105.6	79.44	86.52	86.6	84.19	104.17	97.26	99.18	100.20	88.56	107.54	91.69	95.93	88.84	92.09	87.06	89.33	122.34	127.3	137.08	128.91	138.45	145.44	147.68	143.86
105.6	158.4	63.72	79.27	70.19	71.06	92.54	97.34	94.44	94.77	57.72	64.52	68.9	63.71	77.87	71.81	71.72	73.80	97.4	97.49	98.83	97.91	107.48	107.76	110.62	108.62
158.4	211.2	113.75	104.5	99.72	105.99	190.09	185.08	185.54	186.90	104.16	94.98	100.36	99.83	83.71	87.59	80.63	83.98	103.39	118.88	114.82	112.36	137.42	141.79	138.63	139.28
211.2	264	96.76	109.87	102.6	103.08	83.4	84.63	83.83	83.95	111.8	100.66	102.22	104.89	97.43	103.34	113.82	104.86	66.16	69.1	74	69.75	70.5	67.65	76.39	71.51
264	316.8	78.66	86.18	79.8	81.55	94.13	88.05	93.06	91.75	95.42	97.64	93.55	95.54	108.84	111.6	102.14	107.53	158.1	146.55	156.33	153.66	140.47	139.49	146.23	142.06
316.8	369.6	135.99	133.58	134.21	134.59	139.48	141.32	135.45	138.75	110.81	106.33	103.69	106.94	115.65	129.9	126.37	123.97	137.72	140.79	128.45	135.65	80.4	87.18	80.6	82.73
369.6	422.4	92.98	86.24	86.66	88.63	84.68	77.89	73.97	78.85	106.88	109.54	115.55	110.66	115.11	102.46	118.42	112.00	93.27	91.97	86.76	90.67	103.94	101	95.23	100.06
422.4	475.2	63.09	67.43	64.38	64.97	75.04	86.03	87.75	82.94	148.2	147.4	151.74	149.11	152.22	162.43	160.07	158.24	114.08	104.08	110.37	109.51	78.83	78.72	79.91	79.15
475.2	528	84.27	66.41	55.77	68.82	73.69	79.53	68.83	74.02	153.79	162.75	153.51	156.68	153.02	155.55	153.5	154.02	133.96	136.61	129.64	133.40	80	80.59	80.81	80.47

40 MPH: ARAN IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0.00	52.80	79.78	83.02	67.63	76.81	62.22	68.75	69.92	66.96	59.01	78.87	72.84	70.24	72.39	60.73	52.04	61.72	89.73	102.13	104.96	98.94	129.76	180.41	139.29	149.82
52.80	105.60	129.68	121.76	126.07	125.84	105.30	111.56	101.27	106.04	101.77	107.15	103.3	104.07	96.22	81.79	88.27	88.76	99.33	117.82	95.7	104.28	129.6	127.19	154.91	137.23
105.60	158.40	119.15	100.23	112.48	110.62	117.19	95.31	107.50	106.67	77.7	81.34	78.76	79.27	68.01	76.49	75.35	73.28	103.29	136.36	118.3	119.32	91.91	108.84	113.82	104.86
158.40	211.20	109.94	111.66	119.79	113.80	191.10	191.37	197.42	193.30	94.21	87.02	81.98	87.74	74.68	66.32	72.73	71.24	104.9	87.67	106.6	99.72	127.86	92.95	128.59	116.47
211.20	264.00	102.66	100.44	101.92	101.67	90.22	108.73	91.87	96.94	90.53	97.46	96.04	94.68	101.22	107.46	98.06	102.25	77.99	81.65	75.72	78.45	77.35	85.24	70.43	77.67
264.00	316.80	91.42	95.67	88.27	91.79	97.63	87.02	110.41	98.35	135.78	124.67	98.8	119.75	98.64	121.84	116.05	112.18	160.65	165.07	164.84	163.52	130.07	122.62	134.59	129.09
316.80	369.60	113.26	112.12	113.32	112.90	94.04	84.50	89.46	89.33	119.71	102.26	94.26	105.41	127.52	91.15	119.31	112.66	120.15	75.52	75.81	90.49	133	80.6	94.63	102.74
369.60	422.40	91.40	87.76	98.14	92.43	90.32	81.97	86.97	86.42	89.97	120.31	94.7	101.66	148.77	169.62	148.93	155.77	81.73	91.91	88.23	87.29	127.5	82.53	96.3	102.11
422.40	475.20	66.53	67.58	65.89	66.67	74.40	98.10	90.07	87.52	160.69	148.15	182.03	163.62	188.48	172.19	179.37	180.01	137.6	147.33	144.72	143.22	103.98	94.75	106.16	101.63
475.20	527.71	113.78	89.68	95.04	99.50	110.37	95.70	103.01	103.03	164.67	116.34	148.35	143.12	154.43	143.47	145.46	147.79	134.82	126	134.04	131.62	84.03	108.38	90	94.14

50 MPH: ARAN IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0.00	52.80	72.69	77.76	73.03	74.49	74.65	76.50	94.73	81.96	82.53	111.12	62.95	85.53	60.61	84.71	65.44	70.25	105.04	96.64	112.57	104.75	149.51	131.89	147.68	143.03
52.80	105.60	120.61	124.73	118.88	121.41	100.35	99.18	114.76	104.76	112.79	95.99	98.46	102.41	80.87	118.62	91.64	97.04	99.87	86.06	93.64	93.19	142.68	178.42	173.24	164.78
105.60	158.40	95.94	110.19	111.83	105.99	93.16	104.81	143.14	113.70	73.19	119.87	94.01	95.69	79.59	103.45	73.7	85.58	108.68	103.09	101.32	104.36	111.46	139.19	107.46	119.37
158.40	211.20	127.34	107.55	150.18	128.36	191.45	197.50	258.97	215.97	88.71	136.47	105.09	110.09	62.23	95.07	73.67	76.99	102.05	101.57	103.84	102.49	133.92	128.82	126.25	129.66
211.20	264.00	101.97	98.71	99.85	100.18	82.78	90.36	107.48	93.54	97.39	131.87	89.76	106.34	106.46	122.53	90.38	106.46	74.34	80.26	76.3	76.97	52.85	57.8	60.76	57.14
264.00	316.80	88.71	96.01	94.36	93.03	89.59	86.36	105.13	93.69	114.42	138.81	137.55	130.26	120.44	144.7	136.69	133.94	130.86	163.37	159.5	151.24	159.51	135.04	135.86	143.47
316.80	369.60	108.57	111.84	111.57	110.66	101.29	96.78	98.23	98.77	99.54	118.85	149.37	122.59	122.64	107.49	116.83	115.65	113.02	78.81	78.49	90.11	108.92	90.84	94.61	98.12
369.60	422.40	96.30	92.65	97.77	95.57	98.21	100.07	106.95	101.74	103.32	90.08	98.2	97.20	140.27	115.41	124.27	126.65	75.69	84.58	90.64	83.64	96.24	88.82	101.88	95.65
422.40	475.20	66.77	59.30	67.94	64.67	95.91	96.91	101.42	98.08	143.07	178.36	167.02	162.82	176.22	185.88	199.24	187.11	144.63	161.52	152.18	152.78	92.93	102.96	114.96	103.62
475.20	527.71	105.97	89.91	96.80	97.56	88.87	97.38	93.86	93.37	145.86	158.36	170.61	158.28	147.43	149.05	146.35	147.61	123.46	130.62	145.44	133.17	79.82	144.31	152.8	125.64

60 MPH: ARAN IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0.00	52.80	146.75	56.63	66.94	90.11	88.18	76.20	83.62	82.67	69.16	121.91	87.84	92.97	52.45	64.83	72.11	63.13	97.03	98.85	112.03	102.64	136.87	159.64	132.23	142.91
52.80	105.60	112.64	101.93	94.86	103.14	102.47	109.66	82.07	98.07	92.09	90.7	91.88	91.56	100.12	97.99	109.88	102.66	96.5	77.02	122.98	98.83	160.01	153.2	205.54	172.92
105.60	158.40	134.05	106.83	140.59	127.16	175.67	185.06	164.28	175.00	90.88	82.73	90.57	88.06	88.03	69.53	89.22	82.26	107.56	135.58	89.72	110.95	90.23	126.09	158.66	124.99
158.40	211.20	157.96	175.58	171.06	168.20	239.36	280.25	248.07	255.89	99.34	104.01	84.04	95.80	67.29	81.24	89.66	79.40	100	75.67	123.87	99.85	130.95	90.4	131.53	117.63
211.20	264.00	94.12	112.94	92.70	99.92	94.56	137.67	107.18	113.14	81.13	100.89	87.46	89.83	90.82	105.26	87.38	94.49	71.99	76.42	67.12	71.84	68.79	133.64	65.05	89.16
264.00	316.80	62.67	83.06	82.62	76.12	77.33	87.03	87.09	83.82	141.19	112.71	121.09	125.00	142.9	117.68	141.17	133.92	160.05	150.15	113.62	141.27	125.25	95.33	155.97	125.52
316.80	369.60	114.82	128.10	115.93	119.62	140.22	135.91	150.45	142.19	105.54	90.12	125.82	107.16	113.56	102.79	131.5	115.95	118.16	88.98	128.64	111.93	80.04	106	97.59	94.54
369.60	422.40	97.61	130.10	117.37	115.03	122.35	130.59	120.69	124.54	98.59	180.04	84.01	120.88	130.26	172.81	124.14	142.40	86.7	97.67	78.6	87.66	84.04	68.17	112.83	88.35
422.40	475.20	75.28	76.69	94.30	82.09	95.86	106.05	107.55	103.15	135.57	103.29	149.48	129.45	162.23	128.29	192.97	161.16	165.49	152.15	118.54	145.39	123.22	157.47	89.03	123.24
475.20	527.71	60.08	77.73	59.92	65.91	78.78	69.97	87.79	78.85	150.14	118.45	157.75	142.11	136.53	133.69	152.2	140.81	138.31	118.59	135.3	130.73	152.65	147.57	100.45	133.56

40 MPH: ICC IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	73.42	68.48	79.3	73.73	88.81	91.99	71.27	84.02	53.46	120.05	62.26	78.59	47.86	74.54	48.07	56.82	103.53	107	103.73	104.75	120.03	139.85	148.37	136.08
52.8	105.6	113.47	112.02	114.22	113.24	113.23	115.08	112.19	113.50	96.2	65.37	62.36	74.64	80.33	135.66	126.49	114.16	109.42	101.87	137.84	116.38	145.15	158.45	119.87	141.16
105.6	158.4	96.12	93.25	96.85	95.41	143.59	128.29	132.35	134.74	83.71	64.85	68.81	72.46	59.8	65.47	69.04	64.77	99.67	96.21	95.34	97.07	111.65	115.76	100.31	109.24
158.4	211.2	108.49	126.09	124.72	119.77	264.4	217.98	218.24	233.54	87.02	97.53	102.36	95.64	68.83	71.87	78.64	73.11	111.6	114.76	96.51	107.62	134.99	140.66	126.45	134.03
211.2	264	103.16	89.94	94.38	95.83	117.39	103.89	108.62	109.97	94.47	96.47	99.93	96.96	107.82	120.02	118.13	115.32	75.44	74.99	74.52	74.98	73.67	64.88	71.75	70.10
264	316.8	87.74	94.19	91.31	91.08	125.35	116.26	120.78	120.80	112.18	136.8	119.95	122.98	95.84	94.45	106.21	98.83	164.13	169.45	147.88	160.49	136.48	150.86	141.84	143.06
316.8	369.6	118.72	112.58	114.46	115.25	135.63	113.43	111.3	120.12	91.31	99.06	95.96	95.44	138.65	116.41	124.31	126.46	104.99	79.8	128.05	104.28	75.46	98.67	90.75	88.29
369.6	422.4	89.15	94.22	98.43	93.93	92.88	100.06	103.39	98.78	99.99	92.68	86.62	93.10	115.11	126.44	129.92	123.82	83.08	75.55	82.69	80.44	79.54	82.48	96.86	86.29
422.4	475.2	66.95	58.99	57.21	61.05	89.85	94.62	85.59	90.02	158.63	146.34	160.3	155.09	171.66	180.78	171.7	174.71	132.09	132.48	125.26	129.94	99.28	110.56	110.84	106.89
475.2	527.71	90.75	102.56	109.42	100.91	91.04	135.74	87.6	104.79	146.46	152.98	160.24	153.23	151.14	157.89	151.22	153.42	126.35	119.16	122.85	122.79	96.45	106.49	107.26	103.40

50 MPH: ICC IRI CALCULATED WITH ROADRUF																								
DISTANCE [FT]																								
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	60.97	79.26	80.33	73.52	63.52	70.99	67.26	58.51	91.06	51.84	67.14	54.49	73	53.51	60.33	90.44	96.51	86.71	91.22	118.5	126.33	158	134.28
52.8	105.6	97.42	140.04	130.23	122.56	101.72	111.19	106.46	65.15	72.86	72.82	70.28	122.29	80	79.68	93.99	121.64	119.18	127.52	122.78	136.11	148.07	145.7	143.29
105.6	158.4	87.75	85.82	76.94	83.50	106.71	119.62	113.17	54.47	89.42	80.82	74.90	63.02	63.6	74.11	66.91	101.43	95.49	94.84	97.25	109.31	123.87	117.51	116.90
158.4	211.2	112.26	119.28	117.05	116.20	251.9	214.62	233.26	102.71	86.31	124.55	104.52	79.44	68.65	79.63	75.91	107.67	114.47	111.32	111.15	134.47	133.1	129.53	132.37
211.2	264	93.82	91.39	92.14	92.45	118.16	93.47	105.82	94.7	97.09	105.86	99.22	103.56	105.96	100.13	103.22	71.69	71	74.24	72.31	68.25	66.08	71.22	68.52
264	316.8	88.16	83.85	90.44	87.48	123.62	123.08	123.35	140.76	133.12	89.36	121.08	98.27	92.09	138.77	109.71	146	150.34	142.52	146.29	137.06	139.84	137.3	138.07
316.8	369.6	114.52	126.73	122.02	121.09	138.69	153	145.85	103.73	96.76	115.89	105.46	130.97	140.8	113.1	128.29	117.23	100.27	124.04	113.85	81.36	102.45	77.98	87.26
369.6	422.4	89.28	93.58	91.96	91.61	108.34	105.22	106.78	91.83	100.28	114.02	102.04	122.83	117.59	94.44	111.62	82.99	84.78	86.07	84.61	78.23	85.98	76.3	80.17
422.4	475.2	58.36	71.52	71.16	67.01	86.4	93.48	89.94	149.12	150.15	141.86	147.04	181.08	165.19	184.77	177.01	115.94	120.89	115.03	117.29	100.75	98.69	95.83	98.42
475.2	527.71	108.56	83.38	71.45	87.80	84.88	97.3	91.09	154.72	148.36	169.95	157.68	159.49	144.05	170.63	158.06	129.23	131.4	141.03	133.89	121.52	116.17	97.15	111.61

60 MPH: ICC IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	64	69.39	78.14	70.51	77.1	49.06	61.49	62.55	59.6	42.67	51.04	51.10	47.46	57.65	64.99	56.70	90.66	114.31	89.57	98.18	159.9	137.94	136.38	144.74
52.8	105.6	106.66	134.73	138.22	126.54	104.04	119.79	120.86	114.90	60.23	70.8	66.91	65.98	101.4	80.76	78.87	87.01	137.18	106.75	123.39	122.44	128.55	151.9	143.19	141.21
105.6	158.4	99.88	88.58	86.4	91.62	124.14	141.98	142.53	136.22	57.43	96.97	84.76	79.72	73.45	65.16	72.44	70.35	106.04	97.87	109.9	104.60	108.36	116.01	109.75	111.37
158.4	211.2	134.66	120.22	125.05	126.64	220.38	295.8	227.13	247.77	89.17	86.1	82.99	86.09	75.29	77.62	70.09	74.33	115.02	111.82	114.89	113.91	133.14	136.59	132.53	134.09
211.2	264	90.81	102.19	93.19	95.40	102.31	111.99	112.96	109.09	99.06	94.41	100.08	97.85	104.54	103.78	103.91	104.08	73.54	73.27	73.67	73.49	66.15	69.57	69.93	68.55
264	316.8	84.52	90.55	92.69	89.25	104.33	120.68	121.75	115.59	131.22	134.92	131.43	132.52	94.49	89.35	96.44	93.43	142.58	157.16	144.12	147.95	141.06	140.04	139.93	140.34
316.8	369.6	125.57	118.52	120.59	121.56	138.46	136.13	163.15	145.91	139.75	105.26	108.83	117.95	141.26	134.54	134.89	136.90	127.98	97.18	133.94	119.70	88.34	80.83	92.09	87.09
369.6	422.4	98.83	87.83	89.99	92.22	94.41	104.61	95.57	98.20	88.15	94.38	83.39	88.64	116.05	114.39	122.22	117.55	83.93	85.22	91.57	86.91	100.88	81.44	100.89	94.40
422.4	475.2	61.3	69.27	78.74	69.77	88.89	84.73	95.52	89.71	161.41	151	156.44	156.28	170	170.24	177.48	172.57	128.79	128.02	123.17	126.66	105.39	113.31	98.63	105.78
475.2	527.71	82.37	95.52	92.59	90.16	75.17	85.22	92.04	84.14	155.3	150.38	149.49	151.72	156.28	142.42	150.9	149.87	126.7	121.99	102.81	117.17	113.19	139.19	95.73	116.04

40 MPH: Dynatest IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	73.8	76.21	78.84	76.28	79.27	86.33	78.97	81.52	55.91	62.5	82.25	66.89	72.28	61.49	116.04	83.27	111.53	113.44	88.22	104.40	124.2	158.65	135.27	139.37
52.8	105.6	149.61	124.05	149.44	141.03	115.31	106.86	114.46	112.21	93.32	80.58	58.62	77.51	87.59	68.92	117.42	91.31	118.44	119.14	130.11	122.56	145.65	147.2	132.06	141.64
105.6	158.4	109.84	117.41	110.27	112.51	113.82	108.28	111.03	111.04	85.3	70.8	121.19	92.43	82.72	76.69	83.12	80.84	90.18	93.23	111.11	98.17	112.64	113.79	107.51	111.31
158.4	211.2	137.91	120.26	140.26	132.81	212.39	215.06	213.63	213.69	92.57	87.44	91.3	90.44	81.29	74.38	89.64	81.77	136.49	128.65	123.97	129.70	145.02	142.05	130.88	139.32
211.2	264	94.05	90.63	89.22	91.30	81.87	80.82	83.61	82.10	99.99	106.38	112.63	106.33	96.25	95.41	90.08	93.91	72.15	72.07	71.86	72.03	76.59	80.58	79.18	78.78
264	316.8	68.08	68.87	67.94	68.30	94.76	92.64	90.71	92.70	106.31	110.46	149.12	121.96	99.77	107.89	155.97	121.21	141.42	136.49	146.54	141.48	131.64	131.98	133.01	132.21
316.8	369.6	132.73	130.07	129.81	130.87	133.93	133.94	132.09	133.32	94.69	106.08	120.88	107.22	140.62	137.41	146.88	141.64	104.87	128.39	104.89	112.72	87.9	106.62	84.17	92.90
369.6	422.4	99.04	93.45	92.01	94.83	93.13	92.74	94.84	93.57	102.46	103.68	105.5	103.88	113.78	124.76	108.98	115.84	70.1	83.81	80.44	78.12	77.63	157.08	103.32	112.68
422.4	475.2	72.45	74.73	74.84	74.01	96.61	95.6	97.62	96.61	169.82	155.56	155.57	160.32	182.61	181.64	172.11	178.79	107.19	108.64	104.43	106.75	89.89	100.64	112.22	100.92
475.2	527.71	87.36	80.72	82.81	83.63	98.61	72.61	70.82	80.68	156.49	142.19	163.05	153.91	171.01	161.31	176.42	169.58	131.58	128.69	144.51	134.93	119.41	106.38	93.96	106.58

50 MPH:Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	68.25	66.08	69.12	67.82	82.07	67.84	75.02	74.98	64.16	53.12	67.95	61.74	67.55	66.06	57.66	63.76	112.96	113.34	108.06	111.45	128.2	136.49	127.3	130.66
52.8	105.6	84.9	89.56	107.3	93.92	113.62	116.81	98.93	109.79	86.72	93.83	85.01	88.52	104.01	105.52	71.27	93.60	117.76	120.77	117.85	118.79	158.8	152.34	159.12	156.75
105.6	158.4	108.53	100.64	116.4	108.52	116.9	116.4	101.86	111.72	100.34	90.66	70.5	87.17	83.4	75.36	89.78	82.85	86.57	89.78	91.78	89.38	133.3	111.79	103.84	116.31
158.4	211.2	114.61	114.85	127.91	119.12	208.4	216.56	207.82	210.93	98.29	97.79	88.24	94.77	87.92	87.61	83.75	86.43	129.78	138.05	134.81	134.21	141.77	147.09	147.55	145.47
211.2	264	87.61	91.74	93.62	90.99	80.76	83.28	84.73	82.92	103.6	95.04	99.98	99.54	93.2	102.07	97.6	97.62	74.23	74.06	73.92	74.07	73.54	75.99	73.93	74.49
264	316.8	71.14	70.01	70.47	70.54	92.78	90.52	91.34	91.55	127.43	97.07	96.26	106.92	110.15	100.69	109.66	106.83	136.4	142.01	125.2	134.54	136.22	136.29	141.55	138.02
316.8	369.6	134.07	131.9	135.92	133.96	128.84	134.52	135.77	133.04	96.86	98.11	92.12	95.70	136.14	135.71	150.7	140.85	97.99	104.26	109.45	103.90	90.41	88.56	102.08	93.68
369.6	422.4	99.36	88.11	94.04	93.84	100.35	97.16	88.39	95.30	96.49	98.24	96.21	96.98	111.97	115.69	118.03	115.23	82.64	74.73	65.44	74.27	96	80.03	82.28	86.10
422.4	475.2	76.12	72.88	75.27	74.76	98.39	102.21	100.4	100.33	171.85	169.94	169	170.26	200.94	179.52	176.97	185.81	109.48	113.05	111.21	111.25	99.98	98.09	98.4	98.82
475.2	527.71	76.44	81.12	83.45	80.34	77.13	73.2	75	75.11	153.16	155.81	157.78	155.58	157.32	151.82	177.77	162.30	128.81	143.84	143.59	138.75	106.09	136.33	156.38	132.93

60 MPH: Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S1L1	S1L2	S1L3	Average	S1R1	S1R2	S1R3	Average	S3L1	S3L2	S3L3	Average	S3R1	S3R2	S3R3	Average	S4L1	S4L2	S4L3	Average	S4R1	S4R2	S4R3	Average
0	52.8	65.52	73.23	71.99	70.25	70	54.96	78.84	67.93	69.2	62.07	71.65	67.64	74.78	95.08	82.91	84.26	99.91	94.89	97.02	97.27	169.1	136.5	124.24	143.28
52.8	105.6	100.07	96.6	130.19	108.95	109.66	100.51	118.21	109.46	69.26	67.12	59.32	65.23	92.65	98.89	126.82	106.12	128.18	136.73	138.47	134.46	150.65	127.6	132.77	137.01
105.6	158.4	98.78	91.3	100.02	96.70	110.01	129.26	109.87	116.38	81.31	58.48	107.12	82.30	89.68	105.33	96.57	97.19	110.22	91.77	109.48	103.82	106.21	109.91	105.97	107.36
158.4	211.2	113.47	104.73	114.32	110.84	199.45	199.11	217.15	205.24	85.24	132.12	98.14	105.17	112.95	103.95	88.74	101.88	120.32	119.39	121.21	120.31	130.52	130.54	128.8	129.95
211.2	264	93.18	93.4	95.44	94.01	88.19	85.95	78.93	84.36	115.27	120.23	99.34	111.61	93.11	123.01	90.94	102.35	70.36	70.38	71.33	70.69	84.66	82.96	81.64	83.09
264	316.8	74.44	73.91	72.32	73.56	102.8	95.6	95.41	97.94	135.82	123.02	137.64	132.16	126.2	126.79	138.28	130.42	141.2	141.57	144.06	142.28	130.57	134.98	131.14	132.23
316.8	369.6	136.92	132.36	133.37	134.22	129.68	129.46	130.68	129.94	137.24	100.81	133.1	123.72	131.54	138.48	144.94	138.32	129.45	133.32	120.82	127.86	101.59	98.96	107.09	102.55
369.6	422.4	104.73	91.62	95.55	97.30	102.01	90.69	91.33	94.68	104.55	97.51	105.29	102.45	116.77	109.5	120.22	115.50	85.88	87.03	81.3	84.74	134.73	157.76	130.14	140.88
422.4	475.2	76.13	67.71	72.69	72.18	97.79	84.95	107.13	96.62	157.06	156.44	159.93	157.81	170.32	182.03	177.14	176.50	107.22	111.7	104.2	107.71	107	110.01	108.09	108.37
475.2	527.71	80.96	88.97	88.3	86.08	72.3	79.04	129.48	93.61	163.17	147.29	164.23	158.23	174.04	165.79	170.49	170.11	138.74	129.17	143.97	137.29	104.07	108.93	109.91	107.64

Table C3. IRI Runs - Route 18.

WALKING PROFILER CALCULATED WITH ROADRUF																				
DISTANCE [FT]																				
FROM	TO	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	Average	S25R1	S25R2	S25R3	Average
0	52.8	128.97	121.03	124.22	124.74	329.56	333.23	330.26	331.02	294.9	279.62	220.99	265.17	323.83	410.05	366.94	323.83	410.05	379.75	371.21
52.8	105.6	70.93	66.81	64.65	67.46	373.65	376.27	356.4	368.77	357.23	370.46	366.01	364.57	277.12	288.64	282.88	277.12	288.64	273.3	279.69
105.6	158.4	91.34	103.11	92.34	95.60	375.21	405.87	376.95	386.01	496.26	450.26	479.6	475.37	350.64	307.99	329.32	350.64	307.99	276.72	311.78
158.4	211.2	269.87	273.48	277.43	273.59	279.63	279.2	285.5	281.44	263.16	278.61	280.94	274.24	278.84	301.39	290.12	278.84	301.39	292.7	290.98
211.2	264	184.04	182.36	177.63	181.34	312.79	306.68	329.18	316.22	504.7	391.36	438.87	444.98	260.52	242.05	251.29	260.52	242.05	258.77	253.78
264	316.8	275.47	277.32	280.5	277.76	253.64	247.17	254.98	251.93	232.74	219.9	241.78	231.47	204.35	200.57	202.46	204.35	200.57	210.97	205.30
316.8	369.6	156.61	151.62	147.73	151.99	236.82	248.97	358.97	281.59	512.29	365.49	279.12	385.63	313.75	447.76	380.76	313.75	447.76	307.3	356.27
369.6	422.4	145.24	137.35	128.84	137.14	260.61	245.15	261.93	255.90	287.24	254.75	300.67	280.89	310.33	543.77	427.05	310.33	543.77	719.57	524.56
422.4	475.2	239.3	232.7	221.4	231.13	261	239.35	309.43	269.93	254.22	304.19	304.59	287.67	139.38	153.43	146.41	139.38	153.43	176.44	156.42
475.2	528	319.3	363.82	325.53	336.22	165.64	154.62	154.06	158.11	163.04	180.53	167.69	170.42	164.6	170.65	167.63	164.6	170.65	157.15	164.13

40 MPH: ARAN IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	112.17	180.49	205.72	166.13	170.35	227.17	263.67	220.40	266.27	259.21	226.57	250.68	334.14	276.06	286.31	298.84	275.47	194.32	177.11	215.63	266.45	224.45	222.11	237.67
52.8	105.6	74.67	114.39	102.86	97.31	97.73	157.07	149.14	134.65	218.68	370.94	373.21	320.94	213.33	414.51	257.76	295.20	262.95	248.48	240.43	250.62	221.76	280.78	310.88	271.14
105.6	158.4	140.61	120.18	114.18	124.99	177.34	101.63	178.76	152.58	197.5	240.87	240.23	226.20	573.99	284.72	273.94	377.55	184.84	274.1	278.83	245.92	227.36	149.86	113.62	163.61
158.4	211.2	249.91	252.04	248.98	250.31	248.49	264.76	247.53	253.59	244.03	256.65	238.52	246.40	236.63	407.44	246.59	296.89	156.39	176.61	161.27	164.76	164.75	240.89	240.4	215.35
211.2	264	294.3	190.85	231.62	238.92	634.97	272.13	367.47	424.86	136.82	128.56	129.77	131.72	161.36	173.73	182.44	172.51	164.53	153.97	186.53	168.34	141.92	150.04	276.22	189.39
264	316.8	314.03	252.59	244.61	270.41	321.75	252.82	172.57	249.05	372.96	342.72	338.5	351.39	364.08	263.98	314.22	314.09	206.36	175.91	166.4	182.89	199.33	139.44	130.29	156.35
316.8	369.6	409.58	333.68	317.08	353.45	467.31	212.94	267.11	315.79	331.4	226.08	189.16	248.88	429.55	282	324.16	345.24	107.54	200.05	323.81	210.47	156.28	246.35	152.2	184.94
369.6	422.4	455.87	547.22	486.91	496.67	476.9	586.99	543.38	535.76	477.94	365.23	412.84	418.67	428.71	387.86	406.3	407.62	124.07	100.93	91.19	105.40	206.46	186.45	176.38	189.76
422.4	475.2	177.09	285.42	237.48	233.33	405.98	284.73	244.16	311.62	339.37	548.46	540.67	476.17	621.49	686.85	641.91	650.08	148.17	153.11	164.48	155.25	230.04	235.95	242.45	236.15
475.2	527.71	238.89	410.87	353.86	334.54	590.09	278.36	316.76	395.07	240.21	229.86	258.24	242.77	794.14	599.07	625.78	673.00	531.12	202.56	367.05	366.91	167.3	166.36	200.49	178.05

50 MPH: ARAN IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	229.52	235.05	225.34	229.97	250.42	253.11	260.57	254.70	269.39	249.49	257.88	258.92	236.34	295.71	259.96	264.00	212.22	194.66	213.28	233.68	210.8	247.29	230.59	
52.8	105.6	78.24	81.19	88.7	82.71	145.15	156.45	146.81	149.47	181.13	319.71	172.5	224.45	360.84	256.74	430.07	349.22	227.76	217.54	232.32	225.87	284.09	287.15	288.23	286.49
105.6	158.4	126.78	117.93	110.07	118.26	124.08	113.33	115.16	117.52	246.02	253.56	228.75	242.78	385.89	288.02	293.35	322.42	271.83	276.19	260.56	269.53	175.58	159.63	152.22	162.48
158.4	211.2	254.19	253.75	256.36	254.77	254.36	256.41	245.61	252.13	208.23	220.17	272.92	233.77	249.13	202.02	476.38	309.18	149.58	170.9	159.91	160.13	196.42	246.27	230.54	224.41
211.2	264	227.48	248.64	261.29	245.80	380.58	383.18	423.89	395.88	150.94	154.07	149.68	151.56	147.6	211.53	196.82	185.32	200.11	161.06	172.93	178.03	291.35	146.49	219.4	219.08
264	316.8	258.58	247.77	233.5	246.62	168.34	170.88	492.19	277.14	486.76	317.86	381.57	395.40	234.04	288.29	334.36	285.56	182.67	159.15	162.35	168.06	119.03	121.64	145.43	128.70
316.8	369.6	346.7	335.94	315.01	332.55	272.67	281.18	360.12	304.66	218.42	200.42	179.8	199.55	193.7	289.07	282.24	255.00	312.03	195.19	216.79	241.34	159.84	353.44	242.89	252.06
369.6	422.4	558.34	524.89	622.19	568.47	587.3	571.8	609.08	589.39	512.66	477.33	483.28	491.09	472.93	434.73	412	439.89	97.1	80.49	89.37	88.99	211.31	206.35	188.93	202.20
422.4	475.2	284.08	269.44	241.34	264.95	254.49	253.42	332.04	279.98	424.06	479.94	427.29	443.76	656.76	597.72	576.27	610.25	173.84	146.66	138.51	153.00	186.69	219.78	230.1	212.19
475.2	527.71	382.84	389.81	299.21	357.29	371.2	256.41	420.52	349.38	246.08	276.36	260.99	261.14	605.04	682.94	667.05	651.68	161.47	167.97	343.39	224.28	154.21	190.98	200.16	181.78

60 MPH: ARAN IRI CALCULATED WITH ROADRUF																									
DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	178.27	168.17	212.5	186.31	212.35	221.67	234.39	222.80	292.14	280.53	260	277.56	244.3	265.17	308	272.49	233.36	256.73	267.26	252.45	265.67	276.86	430.62	324.38
52.8	105.6	109.31	111.07	130.12	116.83	197.39	196.43	207.16	200.33	206.95	231.7	242.17	226.94	567.13	563.96	578.45	421.17	271.56	263.97	288.13	274.55	281.51	337.58	293.68	304.26
105.6	158.4	107.44	108.26	76.88	97.53	126.52	127.39	91.56	115.16	280.91	269.43	284.66	278.33	278.31	274.32	250.76	418.82	329.07	317.42	327.75	324.75	189.88	160.03	202.73	184.21
158.4	211.2	253.8	238.06	208.64	233.50	267.95	256.53	269.45	264.64	221.15	265.69	212.01	232.95	262.39	348.26	313.07	287.85	167.83	152.38	169.22	163.14	238.26	228.67	235.02	233.98
211.2	264	136.98	152.19	142.78	143.98	250.76	259.81	191.99	234.19	197.04	193.18	234.68	208.30	182.58	191.65	181.72	246.61	166.83	186.44	200.75	184.67	169.18	286.48	249.07	234.91
264	316.8	281.67	296.44	301.84	293.32	296.32	584.6	363.78	414.90	377.63	287.14	300.77	321.85	267.75	219.03	152.46	199.20	173.74	182.64	180.26	178.88	148.49	128.06	143.64	140.06
316.8	369.6	316.31	334.33	319.15	323.26	213.68	365.15	195.23	258.02	562.04	253.04	204.95	340.01	193.6	243.44	401.76	246.34	177.34	188.17	217.43	194.31	227.62	274.48	233.55	245.22
369.6	422.4	467.08	481.37	358.23	435.56	579.46	626.23	368.38	524.69	383.82	428.6	318.2	376.87	362.33	380.26	399.86	330.21	105.01	89.49	81.66	92.05	190.13	191.64	143.6	175.12
422.4	475.2	348.7	352.37	446.91	382.66	355.61	355.61	508.35	406.52	450.23	535.82	581.04	522.36	562.03	652.68	514.65	478.64	138.61	152.8	137.91	143.11	238.64	283.75	296.5	272.96
475.2	527.71	282.19	319.81	398.17	333.39	431.34	404.25	265.28	366.96	300.18	299.85	330.13	310.05	641.08	625.17	685.8	613.57	188.36	434.67	291.15	304.73	155.44	184.33	171.63	170.47

40 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	84.07	96.94	87.65	89.55	125.3	120.53	110.04	118.62	307.21	275.08	273.56	285.28	290.18	195.55	183.83	223.19	280.05	223.3	299.41	267.59	273.63	441.48	267.61	327.57
52.8	105.6	77.2	73.27	73.36	74.61	60.73	57.12	57.1	58.32	239.97	515.12	351.21	368.77	421.09	336.2	395.87	384.39	265.87	264.11	272.74	267.57	413.19	547.52	434.3	465.00
105.6	158.4	82.04	97.14	95.33	91.50	81.8	91.13	87.61	86.85	393.39	432.01	404.28	409.89	455.07	443.57	468.81	455.82	296.84	246.5	285.04	276.13	340.98	338.35	369.49	349.61
158.4	211.2	254.05	264.43	257.09	258.52	265.81	276.19	254.23	265.41	218.97	230.12	245.06	231.38	308.91	435.37	380.09	374.79	311.58	287.64	302.66	300.63	623.97	706.8	660.55	663.77
211.2	264	155.91	161.85	160.13	159.30	160.29	161.68	184.43	168.80	255.53	194.58	194.12	214.74	619.19	383.86	610.82	537.96	235.01	232.86	242.84	236.90	667.36	657.41	666.82	663.86
264	316.8	231.93	215.01	231.65	226.20	272.35	282.59	275.31	276.75	298.42	306.02	325.99	310.14	233.13	277.95	209.03	240.04	195.68	228.89	226.76	217.11	223.97	250.65	254.98	243.20
316.8	369.6	93.63	80.74	78.01	84.13	138.19	95.44	137.73	123.79	359.48	168.76	206.7	244.98	413.89	280.22	353.3	349.14	208.84	192.91	167.71	189.82	235.74	190.63	214.83	213.73
369.6	422.4	108.61	106.21	105.6	106.81	128.24	162.12	173.23	154.53	233.19	199.91	228.71	220.60	279.06	338.69	256.58	291.44	239.37	205.9	245.17	230.15	132.35	201.38	181.59	171.77
422.4	475.2	221.49	214.34	223.81	219.88	218.15	177.3	196.92	197.46	204.86	251.17	231.5	229.18	180.5	352.76	274.32	269.19	143.74	131.94	127.89	134.52	169.76	122.92	147.17	146.62
475.2	527.71	209.18	210.03	217.05	212.09	382.99	382.61	351.14	372.25	136.98	131.34	133.04	133.79	172.19	133.83	166.67	157.56	159.68	190.93	171.26	173.96	233.48	146.07	151.65	177.07

50 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	87.71	93.75	106.97	96.14	113.28	126.8	114.11	118.06	304.48	285.67	283.55	291.23	288.54	192.81	196.02	225.79	271.27	305.73	290.94	289.31	273.06	454.05	256.81	327.97
52.8	105.6	74.17	75.04	86.21	78.47	55.79	61.93	73.02	63.58	235.41	508.98	344.76	363.05	438.63	332.82	396.56	389.34	266.5	272.24	281.04	273.26	421.66	511.46	407.67	446.93
105.6	158.4	93.86	92.26	69.97	85.36	90.5	89.44	64	81.31	397.38	429.23	412.64	413.08	466.79	417.82	434.39	439.67	308.61	207.21	284.78	266.87	363.99	387.47	339.75	363.74
158.4	211.2	247.56	243.92	261.96	251.15	263.82	251.66	274.81	263.43	268.9	190.59	203.28	220.92	341.81	370.52	311.4	341.24	297.14	319.11	298.39	304.88	614.05	666.67	673.74	651.49
211.2	264	167.63	158.96	160.15	162.25	173.68	175.35	150.87	166.63	207.55	221.46	235.03	221.35	565.93	491.64	725.25	594.27	238.32	223.92	243.46	235.23	650.34	687.51	703.47	680.44
264	316.8	232.57	236.83	214.49	227.96	262.59	266.86	283.1	270.85	413.93	251.14	205.67	290.25	229.62	241.28	207.05	225.98	222.48	200.77	193.79	205.68	261.88	217.36	219.11	232.78
316.8	369.6	82.33	82.96	109.02	91.44	126.82	131.31	166.63	141.59	244.64	232.22	341.66	272.84	417.32	339.04	348.67	368.34	191.75	182.46	200.61	191.61	197.73	238.38	266.12	234.08
369.6	422.4	105.59	106.09	105.19	105.62	149.87	136.48	148.82	145.06	229.34	219.75	222.43	223.84	271.19	243.57	229.07	247.94	238.87	240.59	248.3	242.59	159.36	178.51	155.39	164.42
422.4	475.2	224.12	218.66	213.75	218.84	196.06	207	227.41	210.16	221.96	221.02	218.62	220.53	194.47	423.43	301.08	306.33	131.84	131.57	132.37	131.93	139.67	159.35	180.98	160.00
475.2	527.71	215.69	202.24	168.94	195.62	462	338.88	261.1	353.99	134.39	131.33	131.83	132.52	164.62	145.85	147.31	152.59	166.64	172.69	155.43	164.92	239.3	142.01	137.48	172.93

60 MPH: ICC IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	90.37	98.9	118.26	102.51	119.96	120.43	112.44	117.61	301.57	274.87	254.06	276.83	305.09	196.16	200.11	233.79	256.15	223.03	293.94	257.71	280.68	443.41	261.96	328.68
52.8	105.6	64.81	73.19	87.42	75.14	51.94	56.35	73.71	60.67	244.29	516.82	349.89	370.33	423.79	339.58	401.62	388.33	258.96	264.48	274.5	265.98	393.01	546.37	313.09	417.49
105.6	158.4	105.68	98.2	67.95	90.61	89.25	91.11	65.16	81.84	396.77	432.28	422.45	417.17	475.56	440.9	425.93	447.46	328.48	247.32	283.01	286.27	370.14	338.85	405.97	371.65
158.4	211.2	263.13	263.86	251.19	259.39	286.17	277.65	251.73	271.85	291.97	229.75	201.72	241.15	471.53	436.39	307.4	405.11	280.41	286.26	282.51	283.06	669.06	706.64	672.94	682.88
211.2	264	155.97	159.81	159.88	158.55	151.49	159.84	162.8	158.04	198.73	196.01	237.03	210.59	436.47	382.22	690.79	503.16	250.6	234.17	254.9	246.56	607.01	652.97	712.37	657.45
264	316.8	218.71	215.59	206.78	213.69	293.15	285.24	264.88	281.09	468.33	303.68	212.69	328.23	259.65	279.99	249.76	263.13	220.91	227.84	191.23	213.33	267.28	252.41	237.51	252.40
316.8	369.6	85.62	80.78	126.72	97.71	87.87	92.75	196.62	125.75	181.08	172.54	342.16	231.93	367.4	275.34	350.31	331.02	247.77	204.39	215.23	222.46	180.74	190.34	264.58	211.89
369.6	422.4	111.14	108.31	105.25	108.23	169.75	164.14	136.93	156.94	204.13	195.49	221.54	207.05	295.21	349.71	230.8	291.91	172.46	194.37	242.01	202.95	170.21	200.72	154.3	175.08
422.4	475.2	218.27	212.9	205.38	212.18	184.04	174.89	230.86	196.60	241.43	253.66	211.47	235.52	181.47	347.89	301	276.79	145.12	134.8	131.11	137.01	196.47	121.79	181.15	166.47
475.2	527.71	223.54	210	146.22	193.25	489.22	385.13	225.51	366.62	132.83	129.81	143.47	135.37	157.56	132.76	148.06	146.13	173.51	187.53	161.66	174.23	154.98	144.16	141.53	146.89

40 MPH: Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	102.06	106.02	112.68	106.92	84.64	84.55	78.26	82.48	423.48	457.75	418.39	433.21	485.77	509.75	463.36	486.29	338.28	450.41	436.72	408.47	324.29	437.53	444.68	402.17
52.8	105.6	284.76	291.73	292.63	289.71	316.41	321.79	321.97	320.06	281.36	254.84	298.28	278.16	294.04	287.19	274.6	285.28	351.14	337.5	330.62	339.75	464.06	602.78	560.77	542.54
105.6	158.4	149.91	151.01	147.66	149.53	174.35	170.53	168.84	171.24	204.1	208.97	212.02	208.36	391	488.82	370.6	416.81	258.64	235.82	306.58	267.01	745.98	682.88	665.56	698.14
158.4	211.2	230.63	233.95	233.51	232.70	322.56	324.3	321.95	322.94	283.02	258.27	245.13	262.14	262.33	250.09	274.92	262.45	263.21	256.08	277.05	265.45	292.69	311.33	282.94	295.65
211.2	264	79.22	75.85	75.98	77.02	103.13	101.48	100.29	101.63	159.81	174.67	183.01	172.50	334.68	396.87	380.31	370.62	186.85	222.15	196.73	201.91	226.51	202.83	227.95	219.10
264	316.8	126.61	132.45	129.49	129.52	172.84	182.18	185.67	180.23	234.1	224.85	222.34	227.10	316.31	342.68	362.89	340.63	279.86	252.96	245.71	259.51	180.44	187.01	220.37	195.94
316.8	369.6	222.38	222.43	226.89	223.90	193.25	192.01	194.51	193.26	282.41	291.04	290.79	288.08	293.97	215.51	198.84	236.11	136.65	140.54	142.04	139.74	143.87	195.48	191.96	177.10
369.6	422.4	236.65	248.37	251.17	245.40	447.37	440.83	411.77	433.32	148.02	149.09	150.91	149.34	180.38	159.34	159.09	166.27	187.13	171.54	174.7	177.79	230.85	260.65	200.87	230.79
422.4	475.2	315.35	323.56	321.59	320.17	167.36	205.2	199.04	190.53	339.12	339.24	330.61	336.32	535.68	482.28	441.1	486.35	177.48	179.79	177.28	178.18	131.03	143.59	146.98	140.53
475.2	527.71	329.39	437.02	322.09	362.83	356.92	383.16	353.31	364.46	210.05	263.04	271.84	248.31	195.41	219.6	237.52	217.51	169.9	127.2	123.07	140.06	283.77	178.61	173.96	212.11

50 MPH:Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	106.27	107.89	115.52	109.89	88.43	91.61	93.77	91.27	423.99	425.53	445.92	431.81	517.03	503.34	467.75	496.04	414.73	449.1	444.26	436.03	399.36	459.4	437.59	432.12
52.8	105.6	289.93	292.95	290.74	291.21	323.62	318.33	322.02	321.32	253.08	260.63	243.54	252.42	334.51	324.25	468.73	375.83	319.89	321.88	326.93	322.90	536.45	627.6	586.77	583.61
105.6	158.4	149.78	151.87	147.69	149.78	157.6	160.51	165.8	161.30	215.22	218.92	239.08	224.41	473.64	379.18	563.11	471.98	238.43	255.71	287.27	260.47	667.74	616.49	602.91	629.05
158.4	211.2	235.64	235.39	236.44	235.82	315.52	322.48	322.83	320.28	234.99	219.24	230.98	228.40	275.11	317.86	275.51	289.49	256.55	255.48	264.47	258.83	317.19	300.28	289.76	302.41
211.2	264	76.35	72.02	76.39	74.92	96.98	101.21	99.43	99.21	173.06	184.69	176.86	178.20	335.58	418.19	325.7	359.82	257.15	243.84	240.76	247.25	203.81	202.42	190.29	198.84
264	316.8	127.92	132.39	129.06	129.79	150.09	179.01	169.58	166.23	199.84	211.17	198.45	203.15	361.27	331.95	371	354.74	207.38	205.28	199.46	204.04	187.29	197.18	206.27	196.91
316.8	369.6	227.82	220.23	224.05	224.03	200.06	201.87	201.28	201.07	306.52	297.64	302.21	302.12	250.32	225.34	251.7	242.45	158.18	158.13	156.04	157.45	259.62	268.78	220.7	249.70
369.6	422.4	255.8	256.03	268.21	260.01	398.99	396.58	509.34	434.97	142.01	142.41	140.23	141.55	175.98	174.1	186.84	178.97	159.3	162.06	166.19	162.52	158.69	164.08	161.61	161.46
422.4	475.2	313.7	317.27	309.01	313.33	175.97	163.35	320.53	219.95	314.84	324.97	318.91	319.57	424.78	349.96	405.06	393.27	179.9	182.09	182.98	181.66	151.14	154.84	154.51	153.50
475.2	527.71	304.14	302.54	444.28	350.32	353.88	353.3	397.83	368.34	276.28	289.68	283.08	283.01	260.07	278.37	269.43	269.29	124.51	140.27	137.58	134.12	153.18	191.46	172.86	172.50

60 MPH: Dynatest IRI CALCULATED WITH ROADRUF

DISTANCE [FT]																									
FROM	TO	S23L1	S23L2	S23L3	Average	S23R1	S23R2	S23R3	Average	S24L1	S24L2	S24L3	Average	S24R1	S24R2	S24R3	Average	S25L1	S25L2	S25L3	Average	S25R1	S25R2	S25R3	Average
0	52.8	125.07	109.46	107.23	113.92	92.58	94.77	94.51	93.95	415.88	435.69	438.05	429.87	443.76	469.29	478.09	463.71	369.54	279.89	433.49	360.97	358.09	428.24	449.39	411.91
52.8	105.6	290.36	283.8	287.16	287.11	332.12	315.04	323.57	323.58	283.81	257.39	259.47	266.89	337.67	313.23	315.93	322.28	324.72	332.91	323.73	327.12	525.8	608.99	573.12	569.30
105.6	158.4	151.14	151.91	147.19	150.08	153.68	168.29	161.17	161.05	218.79	222.25	219.83	220.29	373.59	454.96	462.26	430.27	245.98	306.16	255.34	269.16	670.53	676.65	650.78	665.99
158.4	211.2	232.75	235.36	234.35	234.15	314.17	324.35	323.8	320.77	224.7	215.18	218.29	219.39	335.14	262.52	269.29	288.98	252.33	268.11	252.56	257.67	324.43	285.36	291.81	300.53
211.2	264	73.24	70.32	71.91	71.82	97.62	93.96	94.76	95.45	185.88	176.68	170.79	177.78	451.56	392	328.12	390.56	336.3	261.69	253.6	283.86	200.54	203.17	207.25	203.65
264	316.8	119.66	132.24	128.63	126.84	147.44	175.62	147.94	157.00	230.6	227.09	214.65	224.11	401.97	338.45	331.62	357.35	191.7	197.19	192.45	193.78	197.54	193.35	186.75	192.55
316.8	369.6	232.36	226.59	222.35	227.10	214.79	208.87	204.31	209.32	281.84	292.77	297.57	290.73	184.59	210.27	228.23	207.70	154.04	158.43	159.12	157.20	263.84	263.89	232.15	253.29
369.6	422.4	270.09	259.31	262.21	263.87	405.94	411.26	403.05	406.75	142.42	141.01	143.13	142.19	150.14	220.03	180.81	183.66	158.99	162.21	168.26	163.15	167.06	165.26	157.3	163.21
422.4	475.2	313.91	315.07	310.43	313.14	163.28	223.11	218.39	201.59	343.62	349.99	313.63	335.75	555.13	332.67	429.75	439.18	179.41	185.05	230.79	198.42	153.44	164.73	140.59	152.92
475.2	527.71	357.4	407.83	416	393.74	327.99	365.71	363.68	352.46	278.56	309.75	282.13	290.15	248.41	297.95	270.45	272.27	119.21	154.71	219.9	164.61	156.45	288.79	166.61	203.95

Table C4. IRI Difference between Runs - Route 55

WALKING PROFILER Differencess																										
S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R2-R3	Average	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R2	S12R1-R3	S12R2-R3	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R2	S13R1-R3	S13R2-R3	Average	StdDev
13.45	16.68	3.23	11.12	7.02	3.95	3.95	0.55	5.8	5.25	3.87	2.89	6.57	3.33	3.24	4.38	1.90	1.11	0.71	1.82	1.21	0.56	1.2	1.82	3.02	2.01	0.93
7.39	6.84	0.55	4.93	3.80	1.16	1.16	6.36	8.46	2.1	5.64	3.24	7.72	0.85	6.87	5.15	3.75	9.13	0.31	9.44	6.29	5.18	2.18	1.18	3.36	2.24	1.09
5.43	8.37	2.94	5.58	2.72	10.86	10.86	2.37	0.78	3.15	2.10	1.21	4.92	1.89	6.81	4.54	2.48	6.9	6.16	0.74	4.60	3.36	6.76	4.27	11.03	7.35	3.42
2.14	4.1	6.24	4.16	2.05	7.43	7.43	9.47	14.73	5.26	9.82	4.74	0.48	0.89	0.41	0.59	0.26	4.39	1.89	2.5	2.93	1.30	5.37	1.42	3.95	3.58	2.00
4.47	5.36	9.83	6.55	2.87	8.72	8.72	0.38	0.62	0.24	0.41	0.19	3.16	1.54	1.62	2.11	0.91	8.86	13.47	4.61	8.98	4.43	0.75	5.27	4.52	3.51	2.42
3.07	4.23	1.16	2.82	1.55	6.84	6.84	5.69	8.51	2.82	5.67	2.85	4.07	2.94	7.01	4.67	2.10	0.55	11.87	12.42	8.28	6.70	7.6	11.06	3.46	7.37	3.81
2.75	4.68	1.93	3.12	1.41	7.97	7.97	5.77	0.94	4.83	3.85	2.56	3.06	1.21	1.85	2.04	0.94	4.74	4.56	0.18	3.16	2.58	4.55	2.28	2.27	3.03	1.31
5.03	5.09	10.12	6.75	2.92	10.7	10.70	0.73	8.1	7.37	5.40	4.06	1.97	1.07	3.04	2.03	0.99	4.09	1.46	2.63	2.73	1.32	8.36	8.35	0.01	5.57	4.82
11.66	3.37	8.29	7.77	4.17	5	5.00	1.14	14.63	13.49	9.75	7.48	5.62	0.88	6.5	4.33	3.02	2.59	2.73	0.14	1.82	1.46	6.36	2.07	4.29	4.24	2.15
6.62	8.23	1.61	5.49	3.45	4.48	4.48	0.63	0.81	1.44	0.96	0.43	1.81	5.43	3.62	3.62	1.81	5.39	1.05	4.34	3.59	2.26	0.9	4.14	3.24	2.76	1.67

ARAN Differences between runs- 40mph							
S12L1-L2	Average	S12R1-R2	Average	S13L1-L2	Average	S13R1-R2	Average
3.6	3.60	0.65	0.65	9.34	9.34	3.19	3.19
1.09	1.09	8.81	8.81	5.85	5.85	4.13	4.13
1.55	1.55	4.79	4.79	2.08	2.08	4.4	4.40
4.86	4.86	1.38	1.38	6.74	6.74	6.17	6.17
11.6	11.60	4.07	4.07	1.19	1.19	2.26	2.26
3.05	3.05	7.39	7.39	0.2	0.20	0.77	0.77
12.87	12.87	3.87	3.87	9.99	9.99	3.51	3.51
9.31	9.31	3.09	3.09	8.43	8.43	3.14	3.14
0.51	0.51	3.93	3.93	10.46	10.46	8.85	8.85
6.56	6.56	11.05	11.05	0.58	0.58	2.27	2.27

ARAN Differences between runs- 50mph																									
S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R2	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R2	S12R1-R3	S12R2-R3	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R2	S13R1-R3	S13R2-R3	Average	StdDev
1.66	3.55	1.89	2.37	1.03	3.61	7.1	2.25	4.85	4.73	2.43	17.84	4.06	13.78	11.89	7.08	1.13	8.64	7.51	5.76	4.05	15.06	23.15	8.09	15.43	7.54
1.99	2.88	0.89	1.92	1.00	8.16	11.43	7.49	3.94	7.62	3.75	9.47	2.2	7.27	6.31	3.73	5.19	7.56	2.37	5.04	2.60	0.26	0.8	0.54	0.53	0.27
11.35	1.53	9.82	7.57	5.28	3.19	7.59	1.59	9.18	6.12	4.00	3.24	0.45	2.79	2.16	1.50	1.1	3.03	4.13	2.75	1.53	10.59	13.78	3.19	9.19	5.43
22.68	7.38	15.3	15.12	7.65	5.75	5.9	1.63	4.27	3.93	2.15	2.67	5.45	2.78	3.63	1.57	3.04	8.95	11.99	7.99	4.55	8.73	1.48	7.25	5.82	3.83
15.62	4.37	11.25	10.41	5.67	3.15	12.82	8.52	4.3	8.55	4.26	3.01	2.57	0.44	2.01	1.37	2.6	1.57	1.03	1.73	0.80	3.47	11.91	8.44	7.94	4.24
5.77	8.48	2.71	5.65	2.89	5.61	5.94	8.36	2.42	5.57	2.99	7.25	0.23	7.48	4.99	4.12	3.06	13.98	17.04	11.36	7.35	6.54	4.08	2.46	4.36	2.05
7.38	1.77	9.15	6.10	3.85	8.71	6.26	6.49	0.23	4.33	3.55	3.21	1.95	1.26	2.14	0.99	0.16	0.75	0.91	0.61	0.40	1.55	8.92	7.37	5.95	3.89
2.97	9.56	6.59	6.37	3.30	4.66	0.35	0.03	0.32	0.23	0.18	6.18	2.26	3.92	4.12	1.97	2.02	10.07	8.05	6.71	4.19	1.55	1.66	3.21	2.14	0.93
4.49	8.24	12.73	8.49	4.13	3.9	5.21	10.87	5.66	7.25	3.15	0.36	2.17	1.81	1.45	0.96	3.3	3.65	0.35	2.43	1.81	12.52	11.42	1.1	8.35	6.30
5.31	7.5	2.19	5.00	2.67	5.59	6.58	2.12	8.7	5.80	3.36	8.2	28.41	20.21	18.94	10.16	3.9	2.56	1.34	2.60	1.28	3.58	3.31	0.27	2.39	1.84

ARAN Differences between runs- 60mph																													
S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R2	S11R1-R3	S11R2-R3	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R2	S12R1-R3	S12R2-R3	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R2	S13R1-R3	S13R2-R3	Average	StdDev
2.06	2.97	5.03	3.35	1.52	16.06	16.73	0.67	11.15	9.09	3.94	6.64	10.58	7.05	3.34	10.73	5.14	5.59	7.15	3.11	6.85	2.56	9.41	6.27	3.46	0.7	2.55	3.25	2.17	1.32
0.2	22.15	22.35	14.90	12.73	6.75	2.28	4.47	4.50	2.24	2.05	11.94	13.99	9.33	6.38	12.58	13.02	0.44	8.68	7.14	12.66	14.46	27.12	18.08	7.88	5.33	4.04	1.29	3.55	2.06
5.48	6.98	12.46	8.31	3.67	7.37	1.75	9.12	6.08	3.85	20.72	13.74	6.98	13.81	6.87	15.89	4.71	11.18	10.59	5.61	5.92	5.34	11.26	7.51	3.26	9.01	2	7.01	6.01	3.61
21.02	19.52	1.5	14.01	10.86	1.18	2.5	1.32	1.67	0.73	3.16	1.83	1.33	2.11	0.95	8.55	2.25	10.8	7.20	4.43	1.55	13.79	12.24	9.19	6.66	10.11	6.26	3.85	6.74	3.16
19.33	15.22	34.55	23.03	10.18	2	0.45	1.55	1.33	0.80	19.94	17.63	2.31	13.29	9.58	4.46	5.54	1.08	3.69	2.33	1.61	6.91	8.52	5.68	3.62	0.02	0.37	0.35	0.25	0.20
0.72	8.73	8.01	5.82	4.43	0.22	4.58	4.36	3.05	2.46	4.89	0.84	5.73	3.82	2.61	13.31	6.23	7.08	8.87	3.87	5.5	8.64	3.14	5.76	2.76	1.01	7.66	6.65	5.11	3.58
8.87	18.05	26.92	17.95	9.03	1.41	1.72	3.13	2.09	0.92	11.21	2.12	13.33	8.89	5.96	11.75	10.05	1.7	7.83	5.38	3.53	2.41	5.94	3.96	1.80	8.62	4.05	4.57	5.75	2.50
7.25	1.4	8.65	5.77	3.85	7.7	12.41	4.71	8.27	3.88	0.32	8.73	8.41	5.82	4.77	5.83	3.46	9.29	6.19	2.93	3.76	1	4.76	3.17	1.95	1.85	5.16	3.31	3.44	1.66
15.03	9.29	5.74	10.02	4.69	2.05	0.07	1.98	1.37	1.12	14.97	9.25	5.72	9.98	4.67	4.09	1.4	5.49	3.66	2.08	8.34	3.04	11.38	7.59	4.22	1.46	1.72	0.26	1.15	0.78
12.89	3.49	9.4	8.59	4.75	7.46	11.01	3.55	7.34	3.73	10.07	5.21	4.86	6.71	2.91	33.87	14.17	19.7	22.58	10.16	2.08	2.19	0.11	1.46	1.17	1.99	1.51	3.5	2.33	1.04

ICC Difference Between Runs-40mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	S12R1-R	S12R2-R	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R3	S13R2-R3	Average	StdDev
2.56	3.07	0.51	2.05	1.36	3.57	0.2	3.77	2.51	2.01	1.92	3.37	5.29	3.53	1.38	3.05	18.07	15.02	12.05	7.94	6.58	2.69	3.89	4.39	1.99	7.6	7.12	0.48	5.07	3.98
1.42	4.88	6.3	4.20	2.51	1.44	4.69	3.25	3.13	1.63	4.8	0.09	4.89	3.26	2.24	3.35	5.52	2.17	3.68	1.70	2.73	0.09	2.64	1.82	1.50	3.31	5.81	2.5	3.87	1.73
5.43	2.66	2.77	3.62	1.57	7.37	5.71	1.66	4.91	2.94	0.85	0.32	1.17	0.78	0.35	6.07	10.87	4.8	7.25	3.20	0.05	0.84	0.89	0.59	0.47	5.1	1.98	3.12	3.40	1.58
2.59	7.88	5.29	5.25	2.65	1.3	0.78	2.08	1.39	0.65	2.04	3.41	5.45	3.63	1.40	2.37	1.25	3.62	2.41	1.19	0.78	1.16	0.38	0.77	0.39	0.05	0.78	0.83	0.55	0.44
0.23	1.26	1.03	0.84	0.54	1.25	0.2	1.45	0.97	0.67	3.53	3.96	7.49	4.99	1.77	14.76	1.6	13.16	9.84	7.18	3.03	0.87	3.9	2.60	1.56	2.12	0.51	2.63	1.75	1.11
2.36	1.67	0.69	1.57	0.84	19.58	17.77	1.81	13.05	9.78	19.97	7.69	12.28	13.31	5.07	20.7	2.32	18.38	13.80	10.01	0.91	1.33	0.42	0.89	0.46	6.8	3.79	3.01	4.53	2.00
2.44	3.81	1.37	2.54	1.22	12.78	8.67	4.11	8.52	4.34	12.44	3.13	9.31	8.29	3.87	4.83	7.85	12.68	8.45	3.96	2.69	0.21	2.48	1.79	1.38	5.79	8.18	2.39	5.45	2.91
3.84	3.32	7.16	4.77	2.08	8.61	0.74	7.87	5.74	4.35	10.16	10.13	0.03	6.77	4.77	8.14	2.25	5.89	5.43	2.97	4.63	6.56	1.93	4.37	2.33	8.44	9.13	0.69	6.09	4.69
0.21	4.94	4.73	3.29	2.67	0.53	1.24	0.71	0.83	0.37	6.1	1.86	7.96	5.31	2.55	2.15	2.72	0.57	1.81	1.11	1.75	1.52	0.23	1.17	0.82	7.24	8.12	0.88	5.41	3.95
0.97	5.58	6.55	4.37	2.98	0.63	1.61	2.24	1.49	0.81	6.22	3.32	2.9	4.15	1.48	7.78	4.57	12.35	8.23	3.91	4.34	0.14	4.2	2.89	2.39	0.04	3.56	3.52	2.37	2.02

ICC Difference Between Runs-50mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	S12R1-R	S12R2-R	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R3	S13R2-R3	Average	StdDev
14.52	20.51	5.99	13.67	7.30	15.44	1.91	17.35	11.57	8.42	9.1	1.11	7.99	6.07	4.33	7.58	4.93	2.65	5.05	2.47	7.08	4.53	2.55	4.72	2.27	0.4	0.93	1.33	0.89	0.47
0.19	6.72	6.91	4.61	3.83	10.69	11.12	0.43	7.41	6.05	5.52	8.15	2.63	5.43	2.76	0.54	1.78	1.24	1.19	0.62	2.62	3.81	1.19	2.54	1.31	3.85	2.29	1.56	2.57	1.17
2.16	0.99	3.15	2.10	1.08	10.06	11.14	1.08	7.43	5.52	9.96	4.78	5.18	6.64	2.88	11.4	8.87	2.53	7.60	4.57	6.2	9.78	3.58	6.52	3.11	3.19	5.93	2.74	3.95	1.73
6	0.82	5.18	4.00	2.78	2.82	10.83	8.01	7.22	4.06	11.62	13.57	1.95	9.05	6.22	2.6	3.52	0.92	2.35	1.32	1.15	4.19	5.34	3.56	2.16	5.2	2.09	3.11	3.47	1.59
18.68	0.48	19.16	12.77	10.65	7.22	3.12	10.34	6.89	3.62	2.03	3.71	1.68	2.47	1.09	11.69	2.77	8.92	7.79	4.57	3.66	0.98	4.64	3.09	1.89	3.3	18.03	14.73	12.02	7.73
3.1	2.47	5.57	3.71	1.64	6.92	10.11	3.19	6.74	3.46	3.74	1.88	1.86	2.49	1.08	9.98	5.43	4.55	6.65	2.91	3.3	13.37	10.07	8.91	5.13	0.91	7.23	6.32	4.82	3.42
5.16	2.18	7.34	4.89	2.59	5.83	4.56	1.27	3.89	2.35	6.59	7.02	0.43	4.68	3.69	5.17	3.86	1.31	3.45	1.96	7.44	5.06	2.38	4.96	2.53	4.01	1.72	5.73	3.82	2.01
8.75	10.6	1.85	7.07	4.61	2.31	19.26	16.95	12.84	9.19	0.13	2.79	2.66	1.86	1.50	10.28	6.81	3.47	6.85	3.41	1.37	6.83	8.2	5.47	3.61	0.58	1.5	0.92	1.00	0.47
6.84	6.52	0.32	4.56	3.68	5.16	2.47	2.69	3.44	1.49	8.96	8.75	0.21	5.97	4.99	1.78	3.82	5.6	3.73	1.91	7.06	0.4	7.46	4.97	3.97	4.72	0.67	4.05	3.15	2.17
6.33	1.4	4.93	4.22	2.54	6.51	2.08	8.59	5.73	3.32	5.14	10.28	5.14	6.85	2.97	2.26	8.45	6.19	5.63	3.13	2.74	0.49	3.23	2.15	1.46	2.62	4.81	2.19	3.21	1.41

ICC Difference Between Runs-60mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	Average	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R	S13R2-R	Average	StdDev
4.07	2.77	6.84	4.56	2.08	3.63	7.53	3.9	5.02	2.18	10.8	10.72	0.08	7.20	6.17	0.34	0.34	2.52	1.5	1.02	1.68	0.77	17.03	4.76	12.27	11.35	6.19
8.22	6.44	1.78	5.48	3.33	10.22	2.21	8.01	6.81	4.14	6.11	1.03	5.08	4.07	2.69	1.33	1.33	7.33	12.17	4.84	8.11	3.73	14.14	8.37	5.77	9.43	4.28
5.37	8.76	3.39	5.84	2.72	5.03	3.09	8.12	5.41	2.54	8.9	6.55	2.35	5.93	3.32	1.09	1.09	3.94	4.09	0.15	2.73	2.23	18.69	1.56	20.25	13.50	10.37
6.36	8.72	2.36	5.81	3.22	3.99	2.42	6.41	4.27	2.01	6.91	5.53	1.38	4.61	2.88	2.67	2.67	8.06	3.54	4.52	5.37	2.38	0.17	4.89	5.06	3.37	2.78
0.54	11.21	10.67	7.47	6.01	16.07	0.71	15.36	10.71	8.67	0.02	4.67	4.65	3.11	2.68	1.3	1.30	6.32	8.19	1.87	5.46	3.25	2.4	4.43	6.83	4.55	2.22
2.21	3.8	1.59	2.53	1.14	10.77	2.31	13.08	8.72	5.67	9.01	7.63	1.38	6.01	4.07	2.06	2.06	4.25	10.49	6.24	6.99	3.19	10.55	4.15	6.4	7.03	3.25
7.14	7.31	0.17	4.87	4.07	6.86	6.19	0.67	4.57	3.40	13.97	3.81	10.16	9.31	5.13	3.89	3.89	6.02	9.76	3.74	6.51	3.04	1.98	0.4	1.58	1.32	0.82
16.06	15.6	0.46	10.71	8.88	0.76	3.09	3.85	2.57	1.61	5.41	4.43	9.84	6.56	2.88	11.45	11.45	3.01	3.34	6.35	4.23	1.84	2.64	3.21	5.85	3.90	1.71
0.56	4.14	4.7	3.13	2.25	4.51	5.49	0.98	3.66	2.37	2.69	3.21	0.52	2.14	1.43	3.91	3.91	2.84	3.89	1.05	2.59	1.44	3.68	6.59	2.91	4.39	1.94
5.91	6.38	12.29	8.19	3.56	1.92	0.67	1.25	1.28	0.63	0.02	1.94	1.96	1.31	1.11	5.95	5.95	2.72	0.26	2.46	1.81	1.35	5.58	0.09	5.67	3.78	3.20

Dynatest Difference Between Runs-40mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	S12R1-R	S12R2-R	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R3	S13R2-R3	Average	StdDev
0.86	1.21	0.35	0.81	0.43	0.63	0.65	0.02	0.43	0.36	7.69	3.46	4.23	5.13	2.25	5.09	7.64	2.55	5.09	2.55	2.64	0.01	2.63	1.76	1.52	0.47	1.59	2.06	1.37	0.82
0.37	1.26	1.63	1.09	0.65	0.18	0.53	0.71	0.47	0.27	0.75	2.69	3.44	2.29	1.39	2.77	2.09	0.68	1.85	1.07	0.72	1.01	1.73	1.15	0.52	6.34	0.39	6.73	4.49	3.55
0.44	0.63	1.07	0.71	0.32	0.25	2.08	1.83	1.39	0.99	1.22	0.81	2.03	1.35	0.62	0.04	1.13	1.09	0.75	0.62	0.89	0.41	0.48	0.59	0.26	0.07	2.49	2.42	1.66	1.38
1.3	2.18	3.48	2.32	1.10	0.65	0.33	0.32	0.43	0.19	1.69	1.38	0.31	1.13	0.72	1.49	3.72	2.23	2.48	1.14	3.49	5.31	1.82	3.54	1.75	2.65	1.6	4.25	2.83	1.33
1.89	0.41	2.3	1.53	0.99	0.01	2.43	2.44	1.63	1.40	0.91	1.96	2.87	1.91	0.98	4.56	4.77	0.21	3.18	2.57	3.91	1.42	2.49	2.61	1.25	1.19	0.15	1.34	0.89	0.65
1.61	3.13	1.52	2.09	0.90	0.58	0.95	0.37	0.63	0.29	2.01	0.28	2.29	1.53	1.09	0.23	3.92	4.15	2.77	2.20	2.29	1.57	0.72	1.53	0.79	5.52	2.89	2.63	3.68	1.60
1.42	3.35	1.93	2.23	1.00	1.23	0.9	2.13	1.42	0.64	0.21	2.26	2.47	1.65	1.25	5.02	0.57	4.45	3.35	2.42	1.13	1.19	0.06	0.79	0.64	1.15	0.88	0.27	0.77	0.45
2.52	1.62	0.9	1.68	0.81	1.9	3.5	1.6	2.33	1.02	15.24	2.71	12.53	10.16	6.59	1.5	2	3.5	2.33	1.04	1.93	2.02	0.09	1.35	1.09	0.05	1.5	1.55	1.03	0.85
1.99	2.7	0.71	1.80	1.01	3.15	1.21	1.94	2.10	0.98	11.56	1.23	10.33	7.71	5.64	4.94	1.88	3.06	3.29	1.54	1.66	2.21	3.87	2.58	1.15	0.11	6.34	6.23	4.23	3.57
0.7	0.38	0.32	0.47	0.20	2.18	2.29	0.11	1.53	1.23	4.05	4.78	8.83	5.89	2.58	4.11	2.91	1.2	2.74	1.46	0.7	2.21	1.51	1.47	0.76	1.14	3.46	4.6	3.07	1.76

Dynatest Difference Between Runs-50mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	S12R1-R	S12R2-R	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R3	S13R2-R3	Average	StdDev
2.28	1.22	1.06	1.52	0.66	3.32	1.3	2.02	2.21	1.02	12.71	5.54	7.17	8.47	3.76	4.79	4.91	0.12	3.27	2.73	5.89	3.97	1.92	3.93	1.99	3.17	1.1	2.07	2.11	1.04
2.26	1.46	0.8	1.51	0.73	3.34	2.31	1.03	2.23	1.16	5.37	1.74	3.63	3.58	1.82	5.75	1.87	3.88	3.83	1.94	2.58	2.33	4.91	3.27	1.42	3.03	4.31	1.28	2.87	1.52
8.62	6.02	2.6	5.75	3.02	6.14	6.95	0.81	4.63	3.34	0.28	3.73	4.01	2.67	2.08	0.57	0.6	0.03	0.40	0.32	0.28	0.36	0.08	0.24	0.14	1.01	2.12	3.13	2.09	1.06
3.02	2.4	5.42	3.61	1.60	0.1	0.94	0.84	0.63	0.46	2.71	5.1	7.81	5.21	2.55	1.64	1.87	0.23	1.25	0.89	2.5	0.81	1.69	1.67	0.85	0.95	2.03	2.98	1.99	1.02
1.51	0.77	0.74	1.01	0.44	3.99	0.71	3.28	2.66	1.73	0.82	1.49	2.31	1.54	0.75	2.04	2.71	4.75	3.17	1.41	1.36	1.46	2.82	1.88	0.82	2.18	1.43	3.61	2.41	1.11
2.88	1.45	4.33	2.89	1.44	2.72	1.24	1.48	1.81	0.79	3.57	0.34	3.23	2.38	1.77	0.62	4.17	3.55	2.78	1.90	8.55	0.97	7.58	5.70	4.12	0.69	3.67	2.98	2.45	1.56
1.9	0.55	1.35	1.27	0.68	8.27	2.19	6.08	5.51	3.08	1.98	0.14	1.84	1.32	1.02	3.57	0.78	4.35	2.90	1.88	1.36	0.86	2.22	1.48	0.69	2.54	1.49	4.03	2.69	1.28
2.36	0.22	2.14	1.57	1.18	2.77	2.42	0.35	1.85	1.31	4.08	2.77	1.31	2.72	1.39	2.63	0.95	1.68	1.75	0.84	0.61	4.73	5.34	3.56	2.57	0.49	1.49	1	0.99	0.50
3.51	2.31	5.82	3.88	1.78	1.9	2.47	0.57	1.65	0.98	0.7	2.25	1.55	1.50	0.78	0.36	0.04	0.32	0.24	0.17	2.84	4.6	7.44	4.96	2.32	2.17	4.65	6.82	4.55	2.33
4.04	2.77	1.27	2.69	1.39	1.68	2.78	1.1	1.85	0.85	0.5	0.38	0.12	0.33	0.19	1.42	4.13	5.55	3.70	2.10	0.23	0.56	0.33	0.37	0.17	1.72	3.37	1.65	2.25	0.97

Dynatest Difference Between Runs-60mph

S11L1-L2	S11L1-L3	S11L2-L3	Average	StdDev	S11R1-R	S11R1-R	S11R2-R	Average	StdDev	S12L1-L2	S12L1-L3	S12L2-L3	Average	StdDev	S12R1-R	S12R1-R	S12R2-R	Average	StdDev	S13L1-L2	S13L1-L3	S13L2-L3	Average	StdDev	S13R1-R	S13R1-R3	S13R2-R3	Average	StdDev
1.34	1.49	0.15	0.99	0.73	1.71	2.89	4.6	3.07	1.45	2.79	0.74	3.53	2.35	1.45	2.44	2.05	4.49	2.99	1.31	0.07	0.68	0.75	0.50	0.37	0.6	2.72	2.12	1.81	1.09
4.81	1.16	3.65	3.21	1.86	5.06	0.04	5.1	3.40	2.91	2.04	1.85	0.19	1.36	1.02	1.27	0.57	1.84	1.23	0.64	1.46	3.54	2.08	2.36	1.07	0.91	2.63	1.72	1.75	0.86
6.2	2.02	4.18	4.13	2.09	5.56	3.35	2.21	3.71	1.70	1.29	0.21	1.08	0.86	0.57	0.14	3.03	3.17	2.11	1.71	0.81	1.29	0.48	0.86	0.41	0.49	0.87	0.38	0.58	0.26
0.79	5.23	4.44	3.49	2.37	1.85	2.33	4.18	2.79	1.23	0.59	2.9	3.49	2.33	1.53	0.68	3.1	2.42	2.07	1.25	0.34	4.92	5.26	3.51	2.75	1.14	0.31	0.83	0.76	0.42
1.87	5.51	3.64	3.67	1.82	1.34	4.56	3.22	3.04	1.62	1.43	2.27	0.84	1.51	0.72	1.95	4.16	2.21	2.77	1.21	0.47	2.47	2.94	1.96	1.31	2.3	8.52	6.22	5.68	3.14
1.75	2.03	3.78	2.52	1.10	3.11	4.22	1.11	2.81	1.58	1.99	8.94	6.95	5.96	3.58	0.96	0.13	0.83	0.64	0.45	5.58	5.25	0.33	3.72	2.94	0.49	2.3	2.79	1.86	1.21
2.53	0.43	2.1	1.69	1.11	2	3.34	5.34	3.56	1.68	1.31	6.89	5.58	4.59	2.92	1.7	1.64	3.34	2.23	0.96	4.2	5.98	1.78	3.99	2.11	3.25	2.81	0.44	2.17	1.51
5.9	1.35	4.55	3.93	2.34	2.97	0.22	2.75	1.98	1.53	0.46	1.25	0.79	0.83	0.40	2.22	1.54	0.68	1.48	0.77	1.71	3.86	2.15	2.57	1.14	2.78	1.38	1.4	1.85	0.80
4.72	0.43	4.29	3.15	2.36	0.61	2.82	2.21	1.88	1.14	0.61	2.18	1.57	1.45	0.79	1.51	5.97	4.46	3.98	2.27	3.61	0.72	2.89	2.41	1.50	3.07	5.71	2.64	3.81	1.66
0.33	0.02	0.35	0.23	0.19	3.06	2.33	0.73	2.04	1.19	1.14	1.03	0.11	0.76	0.57	1.04	2.89	1.85	1.93	0.93	0.92	0.29	0.63	0.61	0.32	1.6	2.94	1.34	1.96	0.86

Table C5. IRI Difference between Runs - Route 195

WALKING PROFILER Differences

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
4.84	11.04	6.2	7.36	3.26	3.47	1.25	2.22	2.31	1.11	0.04	2.27	2.31	1.54	1.30	2.3	7.6	9.9	6.60	3.90	3.25	1.22	2.03	2.17	1.02	7.72	7.56	15.28	10.19	4.41
7.08	7.16	0.08	4.77	4.06	6.91	4.99	1.92	4.61	2.52	18.98	3.13	15.85	12.65	8.39	3.25	1.78	5.03	3.35	1.63	4.96	14.74	9.78	9.83	4.89	6.99	9.23	2.24	6.15	3.57
15.55	6.47	9.08	10.37	4.67	4.8	1.9	2.9	3.20	1.47	6.8	11.18	4.38	7.45	3.45	6.06	6.15	0.09	4.10	3.47	0.09	1.43	1.34	0.95	0.75	0.28	3.14	2.86	2.09	1.58
9.25	14.03	4.78	9.35	4.63	5.01	4.55	0.46	3.34	2.50	9.18	3.8	5.38	6.12	2.77	3.88	3.08	6.96	4.64	2.05	15.49	11.43	4.06	10.33	5.79	4.37	1.21	3.16	2.91	1.59
13.11	5.84	7.27	8.74	3.85	1.23	0.43	0.8	0.82	0.40	11.14	9.58	1.56	7.43	5.14	5.91	16.39	10.48	10.93	5.25	2.94	7.84	4.9	5.23	2.47	2.85	5.89	8.74	5.83	2.95
7.52	1.14	6.38	5.01	3.40	6.08	1.07	5.01	4.05	2.64	2.22	1.87	4.09	2.73	1.19	2.76	6.7	9.46	6.31	3.37	11.55	1.77	9.78	7.70	5.21	0.98	5.76	6.74	4.49	3.08
2.41	1.78	0.63	1.61	0.90	1.84	4.03	5.87	3.91	2.02	4.48	7.12	2.64	4.75	2.25	14.25	10.72	3.53	9.50	5.46	3.07	9.27	12.34	8.23	4.72	6.78	0.2	6.58	4.52	3.74
6.74	6.32	0.42	4.49	3.53	6.79	10.71	3.92	7.14	3.41	2.66	8.67	6.01	5.78	3.01	12.65	3.31	15.96	10.64	6.56	1.3	6.51	5.21	4.34	2.71	2.94	8.71	5.77	5.81	2.89
4.34	1.29	3.05	2.89	1.53	10.99	12.71	1.72	8.47	5.91	0.8	3.54	4.34	2.89	1.86	10.21	7.85	2.36	6.81	4.03	10	3.71	6.29	6.67	3.16	0.11	1.08	1.19	0.79	0.59
17.86	28.5	10.64	19.00	8.98	5.84	4.86	10.7	7.13	3.13	8.96	0.28	9.24	6.16	5.09	2.53	0.48	2.05	1.69	1.07	2.65	4.32	6.97	4.65	2.18	0.59	0.81	0.22	0.54	0.30

ARAN Differences between runs-40mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
3.24	12.15	15.39	10.26	6.29	6.53	7.7	1.17	5.13	3.48	19.86	13.83	6.03	13.24	6.93	11.66	20.35	8.69	13.57	6.06	12.4	15.23	2.83	10.15	6.50	50.65	9.53	41.12	33.77	21.52
7.92	3.61	4.31	5.28	2.31	6.26	4.03	10.29	6.86	3.17	5.38	1.53	3.85	3.59	1.94	14.43	7.95	6.48	9.62	4.23	18.49	3.63	22.12	14.75	9.80	2.41	25.31	27.72	18.48	13.97
18.92	6.67	12.25	12.61	6.13	21.88	9.69	12.19	14.59	6.44	3.64	1.06	2.58	2.43	1.30	8.48	7.34	1.14	5.65	3.95	33.07	15.01	18.06	22.05	9.67	16.93	21.91	4.98	14.61	8.70
1.72	9.85	8.13	6.57	4.28	0.27	6.32	6.05	4.21	3.42	7.19	12.23	5.04	8.15	3.69	8.36	1.95	6.41	5.57	3.29	17.23	1.7	18.93	12.62	9.50	34.91	0.73	35.64	23.76	19.95
2.22	0.74	1.48	1.48	0.74	18.51	1.65	16.86	12.34	9.29	6.93	5.51	1.42	4.62	2.86	6.24	3.16	9.4	6.27	3.12	3.66	2.27	5.93	3.95	1.85	7.89	6.92	14.81	9.87	4.30
4.25	3.15	7.4	4.93	2.21	10.61	12.78	23.39	15.59	6.84	11.11	36.98	25.87	24.65	12.98	23.2	17.41	5.79	15.47	8.87	4.42	4.19	0.23	2.95	2.36	7.45	4.52	11.97	7.98	3.75
1.14	0.06	1.2	0.80	0.64	9.54	4.58	4.96	6.36	2.76	17.45	25.45	8	16.97	8.74	36.37	8.21	28.16	24.25	14.48	44.63	44.34	0.29	29.75	25.52	52.4	38.37	14.03	34.93	19.41
3.64	6.74	10.38	6.92	3.37	8.35	3.35	5	5.57	2.55	30.34	4.73	25.61	20.23	13.63	20.85	0.16	20.69	13.90	11.90	10.18	6.5	3.68	6.79	3.26	44.97	31.2	13.77	29.98	15.64
1.05	0.64	1.69	1.13	0.53	23.7	15.67	8.03	15.80	7.84	12.54	21.34	33.88	22.59	10.72	16.29	9.11	7.18	10.86	4.80	9.73	7.12	2.61	6.49	3.60	9.23	2.18	11.41	7.61	4.82
24.1	18.74	5.36	16.07	9.65	14.67	7.36	7.31	9.78	4.23	48.33	16.32	32.01	32.22	16.01	10.96	8.97	1.99	7.31	4.71	8.82	0.78	8.04	5.88	4.43	24.35	5.97	18.38	16.23	9.38

ARAN Differences between runs-50mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
5.07	0.34	4.73	3.38	2.64	1.85	20.08	18.23	13.39	10.03	28.59	19.58	48.17	32.11	14.62	24.1	4.83	19.27	16.07	10.03	8.4	7.53	15.93	10.62	4.62	17.62	1.83	15.79	11.75	8.64
4.12	1.73	5.85	3.90	2.07	1.17	14.41	15.58	10.39	8.00	16.8	14.33	2.47	11.20	7.66	37.75	10.77	26.98	25.17	13.58	13.81	6.23	7.58	9.21	4.04	35.74	30.56	5.18	23.83	16.35
14.25	15.89	1.64	10.59	7.80	11.65	49.98	38.33	33.32	19.65	46.68	20.82	25.86	31.12	13.71	23.86	5.89	29.75	19.83	12.43	5.59	7.36	1.77	4.91	2.86	27.73	4	31.73	21.15	14.99
19.79	22.84	42.63	28.42	12.40	6.05	67.52	61.47	45.01	33.88	47.76	16.38	31.38	31.84	15.70	32.84	11.44	21.4	21.89	10.71	0.48	1.79	2.27	1.51	0.93	5.1	7.67	2.57	5.11	2.55
3.26	2.12	1.14	2.17	1.06	7.58	24.7	17.12	16.47	8.58	34.48	7.63	42.11	28.07	18.11	16.07	16.08	32.15	21.43	9.28	5.92	1.96	3.96	3.95	1.98	4.95	7.91	2.96	5.27	2.49
7.3	5.65	1.65	4.87	2.91	3.23	15.54	18.77	12.51	8.20	24.39	23.13	1.26	16.26	13.01	24.26	16.25	8.01	16.17	8.13	32.51	28.64	3.87	21.67	15.54	24.47	23.65	0.82	16.31	13.42
3.27	3	0.27	2.18	1.66	4.51	3.06	1.45	3.01	1.53	19.31	49.83	30.52	33.22	15.44	15.15	5.81	9.34	10.10	4.72	34.21	34.53	0.32	23.02	19.66	18.08	14.31	3.77	12.05	7.42
3.65	1.47	5.12	3.41	1.84	1.86	8.74	6.88	5.83	3.56	13.24	5.12	8.12	8.83	4.11	24.86	16	8.86	16.57	8.02	8.89	14.95	6.06	9.97	4.54	7.42	5.64	13.06	8.71	3.87
7.47	1.17	8.64	5.76	4.02	1	5.51	4.51	3.67	2.37	35.29	23.95	11.34	23.53	11.98	9.66	23.02	13.36	15.35	6.90	16.89	7.55	9.34	11.26	4.96	10.03	22.03	12	14.69	6.44
16.06	9.17	6.89	10.71	4.77	8.51	4.99	3.52	5.67	2.56	12.5	24.75	12.25	16.50	7.15	1.62	1.08	2.7	1.80	0.82	7.16	21.98	14.82	14.65	7.41	64.49	72.98	8.49	48.65	35.04

ARAN Differences between runs-60mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
90.12	79.81	10.31	60.08	43.41	11.98	4.56	7.42	7.99	3.74	52.75	18.68	34.07	35.17	17.06	12.38	19.66	7.28	13.11	6.22	1.82	15	13.18	10.00	7.14	22.77	4.64	27.41	18.27	12.03
10.71	17.78	7.07	11.85	5.45	7.19	20.4	27.59	18.39	10.35	1.39	0.21	1.18	0.93	0.63	2.13	9.76	11.89	7.93	5.13	19.48	26.48	45.96	30.64	13.72	6.81	45.53	52.34	34.89	24.56
27.22	6.54	33.76	22.51	14.21	9.39	11.39	20.78	13.85	6.08	8.15	0.31	7.84	5.43	4.44	18.5	1.19	19.69	13.13	10.35	28.02	17.84	45.86	30.57	14.18	35.86	68.43	32.57	45.62	19.82
17.62	13.1	4.52	11.75	6.65	40.89	8.71	32.18	27.26	16.64	4.67	15.3	19.97	13.31	7.84	13.95	22.37	8.42	14.91	7.02	24.33	23.87	48.2	32.13	13.92	40.55	0.58	41.13	27.42	23.25
18.82	1.42	20.24	13.49	10.48	43.11	12.62	30.49	28.74	15.32	19.76	6.33	13.43	13.17	6.72	14.44	3.44	17.88	11.92	7.54	4.43	4.87	9.3	6.20	2.69	64.85	3.74	68.59	45.73	36.41
20.39	19.95	0.44	13.59	11.39	9.7	9.76	0.06	6.51	5.58	28.48	20.1	8.38	18.99	10.10	25.22	1.73	23.49	16.81	13.09	9.9	46.43	36.53	30.95	18.89	29.92	30.72	60.64	40.43	17.51
13.28	1.11	12.17	8.85	6.73	4.31	10.23	14.54	9.69	5.14	15.42	20.28	35.7	23.80	10.59	10.77	17.94	28.71	19.14	9.03	29.18	10.48	39.66	26.44	14.78	25.96	17.55	8.41	17.31	8.78
32.49	19.76	12.73	21.66	10.02	8.24	1.66	9.9	6.60	4.36	81.45	14.58	96.03	64.02	43.43	42.55	6.12	48.67	32.45	23.00	10.97	8.1	19.07	12.71	5.69	15.87	28.79	44.66	29.77	14.42
1.41	19.02	17.61	12.68	9.79	10.19	11.69	1.5	7.79	5.50	32.28	13.91	46.19	30.79	16.19	33.94	30.74	64.68	43.12	18.74	13.34	46.95	33.61	31.30	16.92	34.25	34.19	68.44	45.63	19.76
17.65	0.16	17.81	11.87	10.14	8.81	9.01	17.82	11.88	5.15	31.69	7.61	39.3	26.20	16.54	2.84	15.67	18.51	12.34	8.35	19.72	3.01	16.71	13.15	8.91	5.08	52.2	47.12	34.80	25.86

ICC Differences between runs-40mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
4.94	5.88	10.82	7.21	3.16	3.18	17.54	20.72	13.81	9.34	66.59	8.8	57.79	44.39	31.14	26.68	0.21	26.47	17.79	15.22	3.47	0.2	3.27	2.31	1.83	19.82	28.34	8.52	18.89	9.94
1.45	0.75	2.2	1.47	0.73	1.85	1.04	2.89	1.93	0.93	30.83	33.84	3.01	22.56	17.00	55.33	46.16	9.17	36.89	24.44	7.55	28.42	35.97	23.98	14.72	13.3	25.28	38.58	25.72	12.65
2.87	0.73	3.6	2.40	1.49	15.3	11.24	4.06	10.20	5.69	18.86	14.9	3.96	12.57	7.72	5.67	9.24	3.57	6.16	2.87	3.46	4.33	0.87	2.89	1.80	4.11	11.34	15.45	10.30	5.74
17.6	16.23	1.37	11.73	9.00	46.42	46.16	0.26	30.95	26.58	10.51	15.34	4.83	10.23	5.26	3.04	9.81	6.77	6.54	3.39	3.16	15.09	18.25	12.17	7.96	5.67	8.54	14.21	9.47	4.35
13.22	8.78	4.44	8.81	4.39	13.5	8.77	4.73	9.00	4.39	2	5.46	3.46	3.64	1.74	12.2	10.31	1.89	8.13	5.49	0.45	0.92	0.47	0.61	0.27	8.79	1.92	6.87	5.86	3.54
6.45	3.57	2.88	4.30	1.89	9.09	4.57	4.52	6.06	2.62	24.62	7.77	16.85	16.41	8.43	1.39	10.37	11.76	7.84	5.63	5.32	16.25	21.57	14.38	8.28	14.38	5.36	9.02	9.59	4.54
6.14	4.26	1.88	4.09	2.13	22.2	24.33	2.13	16.22	12.25	7.75	4.65	3.1	5.17	2.37	22.24	14.34	7.9	14.83	7.18	25.19	23.06	48.25	32.17	13.97	23.21	15.29	7.92	15.47	7.65
5.07	9.28	4.21	6.19	2.71	7.18	10.51	3.33	7.01	3.59	7.31	13.37	6.06	8.91	3.91	11.33	14.81	3.48	9.87	5.80	7.53	0.39	7.14	5.02	4.01	2.94	17.32	14.38	11.55	7.60
7.96	9.74	1.78	6.49	4.18	4.77	4.26	9.03	6.02	2.62	12.29	1.67	13.96	9.31	6.67	9.12	0.04	9.08	6.08	5.23	0.39	6.83	7.22	4.81	3.84	11.28	11.56	0.28	7.71	6.43
11.81	18.67	6.86	12.45	5.93	44.7	3.44	48.14	32.09	24.87	6.52	13.78	7.26	9.19	4.00	6.75	0.08	6.67	4.50	3.83	7.19	3.5	3.69	4.79	2.08	10.04	10.81	0.77	7.21	5.59

ICC Differences between runs-50mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	Average	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev
18.29	19.36	1.07	12.91	10.26	7.47	7.47	32.55	6.67	39.22	26.15	17.19	18.51	0.98	19.49	12.99	10.42	6.07	3.73	9.8	6.53	3.06	7.83	39.5	31.67	26.33	16.50
42.62	32.81	9.81	28.41	16.84	9.47	9.47	7.71	7.67	0.04	5.14	4.42	42.29	42.61	0.32	28.41	24.32	2.46	5.88	8.34	5.56	2.95	11.96	9.59	2.37	7.97	5.00
1.93	10.81	8.88	7.21	4.67	12.91	12.91	34.95	26.35	8.6	23.30	13.44	0.58	11.09	10.51	7.39	5.91	5.94	6.59	0.65	4.39	3.26	14.56	8.2	6.36	9.71	4.30
7.02	4.79	2.23	4.68	2.40	37.28	37.28	16.4	21.84	38.24	25.49	11.37	10.79	0.19	10.98	7.32	6.18	6.8	3.65	3.15	4.53	1.98	1.37	4.94	3.57	3.29	1.80
2.43	1.68	0.75	1.62	0.84	24.69	24.69	2.39	11.16	8.77	7.44	4.53	2.4	3.43	5.83	3.89	1.76	0.69	2.55	3.24	2.16	1.32	2.17	2.97	5.14	3.43	1.54
4.31	2.28	6.59	4.39	2.16	0.54	0.54	7.64	51.4	43.76	34.27	23.37	6.18	40.5	46.68	31.12	21.82	4.34	3.48	7.82	5.21	2.30	2.78	0.24	2.54	1.85	1.40
12.21	7.5	4.71	8.14	3.79	14.31	14.31	6.97	12.16	19.13	12.75	6.10	9.83	17.87	27.7	18.47	8.95	16.96	6.81	23.77	15.85	8.53	21.09	3.38	24.47	16.31	11.33
4.3	2.68	1.62	2.87	1.35	3.12	3.12	8.45	22.19	13.74	14.79	6.93	5.24	28.39	23.15	18.93	12.14	1.79	3.08	1.29	2.05	0.92	7.75	1.93	9.68	6.45	4.03
13.16	12.8	0.36	8.77	7.29	7.08	7.08	1.03	7.26	8.29	5.53	3.93	15.89	3.69	19.58	13.05	8.32	4.95	0.91	5.86	3.91	2.63	2.06	4.92	2.86	3.28	1.48
25.18	37.11	11.93	24.74	12.60	12.42	12.42	6.36	15.23	21.59	14.39	7.65	15.44	11.14	26.58	17.72	7.97	2.17	11.8	9.63	7.87	5.05	5.35	24.37	19.02	16.25	9.81

ICC Differences between runs-60mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
5.39	14.14	8.75	9.43	4.41	28.04	15.61	12.43	18.69	8.25	16.93	8.56	8.37	11.29	4.89	10.19	17.53	7.34	11.69	5.26	23.65	1.09	24.74	16.49	13.35	21.96	23.52	1.56	15.68	12.25
28.07	31.56	3.49	21.04	15.30	15.75	16.82	1.07	11.21	8.80	10.57	6.68	3.89	7.05	3.36	20.64	22.53	1.89	15.02	11.41	30.43	13.79	16.64	20.29	8.90	23.35	14.64	8.71	15.57	7.36
11.3	13.48	2.18	8.99	5.99	17.84	18.39	0.55	12.26	10.14	39.54	27.33	12.21	26.36	13.69	8.29	1.01	7.28	5.53	3.94	8.17	3.86	12.03	8.02	4.09	7.65	1.39	6.26	5.10	3.29
14.44	9.61	4.83	9.63	4.81	75.42	6.75	68.67	50.28	37.85	3.07	6.18	3.11	4.12	1.78	2.33	5.2	7.53	5.02	2.60	3.2	0.13	3.07	2.13	1.74	3.45	0.61	4.06	2.71	1.84
11.38	2.38	9	7.59	4.66	9.68	10.65	0.97	7.10	5.33	4.65	1.02	5.67	3.78	2.44	0.76	0.63	0.13	0.51	0.33	0.27	0.13	0.4	0.27	0.14	3.42	3.78	0.36	2.52	1.88
6.03	8.17	2.14	5.45	3.06	16.35	17.42	1.07	11.61	9.15	3.7	0.21	3.49	2.47	1.96	5.14	1.95	7.09	4.73	2.59	14.58	1.54	13.04	9.72	7.13	1.02	1.13	0.11	0.75	0.56
7.05	4.98	2.07	4.70	2.50	2.33	24.69	27.02	18.01	13.63	34.49	30.92	3.57	22.99	16.92	6.72	6.37	0.35	4.48	3.58	30.8	5.96	36.76	24.51	16.34	7.51	3.75	11.26	7.51	3.76
11	8.84	2.16	7.33	4.61	10.2	1.16	9.04	6.80	4.92	6.23	4.76	10.99	7.33	3.26	1.66	6.17	7.83	5.22	3.19	1.29	7.64	6.35	5.09	3.36	19.44	0.01	19.45	12.97	11.22
7.97	17.44	9.47	11.63	5.09	4.16	6.63	10.79	7.19	3.35	10.41	4.97	5.44	6.94	3.01	0.24	7.48	7.24	4.99	4.11	0.77	5.62	4.85	3.75	2.61	7.92	6.76	14.68	9.79	4.28
13.15	10.22	2.93	8.77	5.26	10.05	16.87	6.82	11.25	5.13	4.92	5.81	0.89	3.87	2.62	13.86	5.38	8.48	9.24	4.29	4.71	23.89	19.18	15.93	10.00	26	17.46	43.46	28.97	13.25

Dynatest Differences between runs-40mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
2.41	5.04	2.63	3.36	1.46	7.06	0.3	7.36	4.91	3.99	6.59	26.34	19.75	17.56	10.06	10.79	43.76	54.55	36.37	22.80	1.91	23.31	25.22	16.81	12.94	34.45	11.07	23.38	22.97	11.70
25.56	0.17	25.39	17.04	14.61	8.45	0.85	7.6	5.63	4.16	12.74	34.7	21.96	23.13	11.03	18.67	29.83	48.5	32.33	15.07	0.7	11.67	10.97	7.78	6.14	1.55	13.59	15.14	10.09	7.44
7.57	0.43	7.14	5.05	4.00	5.54	2.79	2.75	3.69	1.60	14.5	35.89	50.39	33.59	18.05	6.03	0.4	6.43	4.29	3.37	3.05	20.93	17.88	13.95	9.56	1.15	5.13	6.28	4.19	2.69
17.65	2.35	20	13.33	9.58	2.67	1.24	1.43	1.78	0.78	5.13	1.27	3.86	3.42	1.97	6.91	8.35	15.26	10.17	4.46	7.84	12.52	4.68	8.35	3.94	2.97	14.14	11.17	9.43	5.79
3.42	4.83	1.41	3.22	1.72	1.05	1.74	2.79	1.86	0.88	6.39	12.64	6.25	8.43	3.65	0.84	6.17	5.33	4.11	2.87	0.08	0.29	0.21	0.19	0.11	3.99	2.59	1.4	2.66	1.30
0.79	0.14	0.93	0.62	0.42	2.12	4.05	1.93	2.70	1.17	4.15	42.81	38.66	28.54	21.22	8.12	56.2	48.08	37.47	25.74	4.93	5.12	10.05	6.70	2.90	0.34	1.37	1.03	0.91	0.52
2.66	2.92	0.26	1.95	1.47	0.01	1.84	1.85	1.23	1.06	11.39	26.19	14.8	17.46	7.75	3.21	6.26	9.47	6.31	3.13	23.52	0.02	23.5	15.68	13.56	18.72	3.73	22.45	14.97	9.91
5.59	7.03	1.44	4.69	2.90	0.39	1.71	2.1	1.40	0.90	1.22	3.04	1.82	2.03	0.93	10.98	4.8	15.78	10.52	5.50	13.71	10.34	3.37	9.14	5.27	79.45	25.69	53.76	52.97	26.89
2.28	2.39	0.11	1.59	1.29	1.01	1.01	2.02	1.35	0.58	14.26	14.25	0.01	9.51	8.22	0.97	10.5	9.53	7.00	5.24	1.45	2.76	4.21	2.81	1.38	10.75	22.33	11.58	14.89	6.46
6.64	4.55	2.09	4.43	2.28	26	27.79	1.79	18.53	14.52	14.3	6.56	20.86	13.91	7.16	9.7	5.41	15.11	10.07	4.86	2.89	12.93	15.82	10.55	6.79	13.03	25.45	12.42	16.97	7.35

Dynatest Differences between runs-50mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
2.17	0.87	3.04	2.03	1.09	14.23	7.05	7.18	9.49	4.11	11.04	3.79	14.83	9.89	5.61	1.49	9.89	8.4	6.59	4.48	0.38	4.9	5.28	3.52	2.73	8.29	0.9	9.19	6.13	4.55
4.66	22.4	17.74	14.93	9.20	3.19	14.69	17.88	11.92	7.73	7.11	1.71	8.82	5.88	3.71	1.51	32.74	34.25	22.83	18.48	3.01	0.09	2.92	2.01	1.66	6.46	0.32	6.78	4.52	3.64
7.89	7.87	15.76	10.51	4.55	0.5	15.04	14.54	10.03	8.25	9.68	29.84	20.16	19.89	10.08	8.04	6.38	14.42	9.61	4.24	3.21	5.21	2	3.47	1.62	21.51	29.46	7.95	19.64	10.88
0.24	13.3	13.06	8.87	7.47	8.16	0.58	8.74	5.83	4.55	0.5	10.05	9.55	6.70	5.38	0.31	4.17	3.86	2.78	2.14	8.27	5.03	3.24	5.51	2.55	5.32	5.78	0.46	3.85	2.95
4.13	6.01	1.88	4.01	2.07	2.52	3.97	1.45	2.65	1.26	8.56	3.62	4.94	5.71	2.56	8.87	4.4	4.47	5.91	2.56	0.17	0.31	0.14	0.21	0.09	2.45	0.39	2.06	1.63	1.09
1.13	0.67	0.46	0.75	0.34	2.26	1.44	0.82	1.51	0.72	30.36	31.17	0.81	20.78	17.30	9.46	0.49	8.97	6.31	5.04	5.61	11.2	16.81	11.21	5.60	0.07	5.33	5.26	3.55	3.02
2.17	1.85	4.02	2.68	1.17	5.68	6.93	1.25	4.62	2.98	1.25	4.74	5.99	3.99	2.46	0.43	14.56	14.99	9.99	8.28	6.27	11.46	5.19	7.64	3.35	1.85	11.67	13.52	9.01	6.27
11.25	5.32	5.93	7.50	3.26	3.19	11.96	8.77	7.97	4.44	1.75	0.28	2.03	1.35	0.94	3.72	6.06	2.34	4.04	1.88	7.91	17.2	9.29	11.47	5.01	15.97	13.72	2.25	10.65	7.36
3.24	0.85	2.39	2.16	1.21	3.82	2.01	1.81	2.55	1.11	1.91	2.85	0.94	1.90	0.96	21.42	23.97	2.55	15.98	11.70	3.57	1.73	1.84	2.38	1.03	1.89	1.58	0.31	1.26	0.84
4.68	7.01	2.33	4.67	2.34	3.93	2.13	1.8	2.62	1.15	2.65	4.62	1.97	3.08	1.38	5.5	20.45	25.95	17.30	10.58	15.03	14.78	0.25	10.02	8.46	30.24	50.29	20.05	33.53	15.39

Dynatest Differences between runs-60mph

S1L1-S1L	S1L1-S1L	S1L2-S1L	Average	StdDev	S1R1-S1R	S1R1-S1R	S1R2-S1R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R	S3R2-S3R	Average	StdDev	S3L1-S3L	S3L1-S3L	S3L2-S3L	Average	StdDev	S3R1-S3R	S3R1-S3R3	S3R2-S3R3	Average	StdDev
7.71	6.47	1.24	5.14	3.43	15.04	8.84	23.88	15.92	7.56	7.13	2.45	9.58	6.39	3.62	20.3	8.13	12.17	13.53	6.20	5.02	2.89	2.13	3.35	1.50	32.6	44.86	12.26	29.91	16.47
3.47	30.12	33.59	22.39	16.48	9.15	8.55	17.7	11.80	5.12	2.14	9.94	7.8	6.63	4.03	6.24	34.17	27.93	22.78	14.66	8.55	10.29	1.74	6.86	4.52	23.05	17.88	5.17	15.37	9.20
7.48	1.24	8.72	5.81	4.01	19.25	0.14	19.39	12.93	11.07	22.83	25.81	48.64	32.43	14.12	15.65	6.89	8.76	10.43	4.61	18.45	0.74	17.71	12.30	10.02	3.7	0.24	3.94	2.63	2.07
8.74	0.85	9.59	6.39	4.82	0.34	17.7	18.04	12.03	10.12	46.88	12.9	33.98	31.25	17.15	9	24.21	15.21	16.14	7.65	0.93	0.89	1.82	1.21	0.53	0.02	1.72	1.74	1.16	0.99
0.22	2.26	2.04	1.51	1.12	2.24	9.26	7.02	6.17	3.59	4.96	15.93	20.89	13.93	8.15	29.9	2.17	32.07	21.38	16.67	0.02	0.97	0.95	0.65	0.54	1.7	3.02	1.32	2.01	0.89
0.53	2.12	1.59	1.41	0.81	7.2	7.39	0.19	4.93	4.10	12.8	1.82	14.62	9.75	6.92	0.59	12.08	11.49	8.05	6.47	0.37	2.86	2.49	1.91	1.34	4.41	0.57	3.84	2.94	2.07
4.56	3.55	1.01	3.04	1.83	0.22	1	1.22	0.81	0.53	36.43	4.14	32.29	24.29	17.57	6.94	13.4	6.46	8.93	3.88	3.87	8.63	12.5	8.33	4.32	2.63	5.5	8.13	5.42	2.75
13.11	9.18	3.93	8.74	4.61	11.32	10.68	0.64	7.55	5.99	7.04	0.74	7.78	5.19	3.87	7.27	3.45	10.72	7.15	3.64	1.15	4.58	5.73	3.82	2.38	23.03	4.59	27.62	18.41	12.19
8.42	3.44	4.98	5.61	2.55	12.84	9.34	22.18	14.79	6.64	0.62	2.87	3.49	2.33	1.51	11.71	6.82	4.89	7.81	3.52	4.48	3.02	7.5	5.00	2.28	3.01	1.09	1.92	2.01	0.96
8.01	7.34	0.67	5.34	4.06	6.74	57.18	50.44	38.12	27.38	15.88	1.06	16.94	11.29	8.88	8.25	3.55	4.7	5.50	2.45	9.57	5.23	14.8	9.87	4.79	4.86	5.84	0.98	3.89	2.57

Table C6. IRI Difference between Runs - Route 18

WALKING PROFILER Differences																					
S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	Average
7.94	4.75	3.19	5.29	2.42	3.67	0.7	2.97	2.45	1.55	15.28	73.91	58.63	49.27	30.41	86.22	323.83	410.05	273.37	167.71	86.22	86.22
4.12	6.28	2.16	4.19	2.06	2.62	17.25	19.87	13.25	9.30	13.23	8.78	4.45	8.82	4.39	11.52	277.12	288.64	192.43	156.78	11.52	11.52
11.77	1	10.77	7.85	5.95	30.66	1.74	28.92	20.44	16.22	46	16.66	29.34	30.67	14.71	42.65	350.64	307.99	233.76	166.87	42.65	42.65
3.61	7.56	3.95	5.04	2.19	0.43	5.87	6.3	4.20	3.27	15.45	17.78	2.33	11.85	8.33	22.55	278.84	301.39	200.93	154.89	22.55	22.55
1.68	6.41	4.73	4.27	2.40	6.11	16.39	22.5	15.00	8.28	113.34	65.83	47.51	75.56	33.98	18.47	260.52	242.05	173.68	134.73	18.47	18.47
1.85	5.03	3.18	3.35	1.60	6.47	1.34	7.81	5.21	3.42	12.84	9.04	21.88	14.59	6.60	3.78	204.35	200.57	136.23	114.72	3.78	3.78
4.99	8.88	3.89	5.92	2.62	12.15	122.15	110	81.43	60.31	146.8	233.17	86.37	155.45	73.78	134.01	313.75	447.76	298.51	157.43	134.01	134.01
7.89	16.4	8.51	10.93	4.74	15.46	1.32	16.78	11.19	8.57	32.49	13.43	45.92	30.61	16.33	233.44	310.33	543.77	362.51	161.61	233.44	233.44
6.6	17.9	11.3	11.93	5.68	21.65	48.43	70.08	46.72	24.26	49.97	50.37	0.4	33.58	28.74	14.05	139.38	153.43	102.29	76.74	14.05	14.05
44.52	6.23	38.29	29.68	20.55	11.02	11.58	0.56	7.72	6.21	17.49	4.65	12.84	11.66	6.50	6.05	164.6	170.65	113.77	93.33	6.05	6.05

ARAN Differences between runs-40mph																													
S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	S25R1-R3	S25R2-R3	Average	StdDev
68.32	93.55	25.23	62.37	34.55	56.82	93.32	36.5	62.21	28.79	7.06	39.7	32.64	26.47	17.17	58.08	47.83	10.25	38.72	25.18	81.15	98.36	17.21	65.57	42.76	42	44.34	2.34	29.56	23.60
39.72	28.19	11.53	26.48	14.17	59.34	51.41	7.93	39.56	27.68	152.26	154.53	2.27	103.02	87.26	201.18	44.43	156.75	134.12	80.79	14.47	22.52	8.05	15.01	7.25	59.02	89.12	30.1	59.41	29.51
20.43	26.43	6	17.62	10.50	75.71	1.42	77.13	51.42	43.31	43.37	42.73	0.64	28.91	24.49	289.27	300.05	10.78	200.03	163.99	89.26	93.99	4.73	62.66	50.22	77.5	113.74	36.24	75.83	38.78
2.13	0.93	3.06	2.04	1.07	16.27	0.96	17.23	11.49	9.13	12.62	5.51	18.13	12.09	6.33	170.81	9.96	160.85	113.87	90.13	20.22	4.88	15.34	13.48	7.84	76.14	75.65	0.49	50.76	43.54
103.45	62.68	40.77	68.97	31.81	362.84	267.5	95.34	241.89	135.58	8.26	7.05	1.21	5.51	3.77	12.37	21.08	8.71	14.05	6.35	10.56	22	32.56	21.71	11.00	8.12	134.3	126.18	89.53	70.62
61.44	69.42	7.98	46.28	33.41	68.93	149.18	80.25	99.45	43.43	30.24	34.46	4.22	22.97	16.38	100.1	49.86	50.24	66.73	28.90	30.45	39.96	9.51	26.64	15.58	59.89	69.04	9.15	46.03	32.26
75.9	92.5	16.6	61.67	39.90	254.37	200.2	54.17	169.58	103.55	105.32	142.24	36.92	94.83	53.44	147.55	105.39	42.16	98.37	53.04	92.51	216.27	123.76	144.18	64.36	90.07	4.08	94.15	62.77	50.87
91.35	31.04	60.31	60.90	30.16	110.09	66.48	43.61	73.39	33.77	112.71	65.1	47.61	75.14	33.69	40.85	22.41	18.44	27.23	11.96	23.14	32.88	9.74	21.92	11.62	20.01	30.08	10.07	20.05	10.01
108.33	60.39	47.94	72.22	31.89	121.25	161.82	40.57	107.88	61.72	209.09	201.3	7.79	139.39	114.04	65.36	20.42	44.94	43.57	22.50	4.94	16.31	11.37	10.87	5.70	5.91	12.41	6.5	8.27	3.59
171.98	114.97	57.01	114.65	57.49	311.73	273.33	38.4	207.82	147.97	10.35	18.03	28.38	18.92	9.05	195.07	168.36	26.71	130.05	90.48	328.56	164.07	164.49	219.04	94.85	0.94	33.19	34.13	22.75	18.90

ARAN Differences between runs-50mph																													
S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	S25R1-R3	S25R2-R3	Average	StdDev
5.53	4.18	9.71	6.47	2.88	2.69	10.15	7.46	6.77	3.78	19.9	11.51	8.39	13.27	5.95	59.37	23.62	35.75	39.58	18.18	20.74	38.3	17.56	25.53	11.17	22.88	13.61	36.49	24.33	11.51
2.95	10.46	7.51	6.97	3.78	11.3	1.66	9.64	7.53	5.15	138.58	8.63	147.21	98.14	77.64	104.1	69.23	173.33	115.55	52.99	10.22	4.56	14.78	9.85	5.12	3.06	4.14	1.08	2.76	1.55
8.85	16.71	7.86	11.14	4.85	10.75	8.92	1.83	7.17	4.71	7.54	17.27	24.81	16.54	8.66	97.87	92.54	5.33	65.25	51.96	4.36	11.27	15.63	10.42	5.68	15.95	23.36	7.41	15.57	7.98
0.44	2.17	2.61	1.74	1.15	2.05	8.75	10.8	7.20	4.58	11.94	64.69	52.75	43.13	27.66	47.11	227.25	274.36	182.91	119.94	21.32	10.33	10.99	14.21	6.16	49.85	34.12	15.73	33.23	17.08
21.16	33.81	12.65	22.54	10.65	2.6	43.31	40.71	28.87	22.79	3.13	1.26	4.39	2.93	1.57	63.93	49.22	14.71	42.62	25.27	39.05	27.18	11.87	26.03	13.63	144.86	71.95	72.91	96.57	41.82
10.81	25.08	14.27	16.72	7.44	2.54	323.85	321.31	215.90	184.78	168.9	105.19	63.71	112.60	52.99	54.25	100.32	46.07	66.88	29.25	23.52	20.32	3.2	15.68	10.93	2.61	26.4	23.79	17.60	13.05
10.76	31.69	20.93	21.13	10.47	8.51	87.45	78.94	58.30	43.33	18	38.62	20.62	25.75	11.23	95.37	88.54	6.83	63.58	49.27	116.84	95.24	21.6	77.89	49.93	193.6	83.05	110.55	129.07	57.55
33.45	63.85	97.3	64.87	31.94	15.5	21.78	37.28	24.85	11.21	35.33	29.38	5.95	23.55	15.53	38.2	60.93	22.73	40.62	19.21	16.61	7.73	8.88	11.07	4.83	4.96	22.38	17.42	14.92	8.98
14.64	42.74	28.1	28.49	14.05	1.07	77.55	78.62	52.41	44.47	55.88	3.23	52.65	37.25	29.51	59.04	80.49	21.45	53.66	29.89	27.18	35.33	8.15	23.55	13.95	33.09	43.41	10.32	28.94	16.93
6.97	83.63	90.6	60.40	46.40	114.79	49.32	164.11	109.41	57.58	30.28	14.91	15.37	20.19	8.74	77.9	62.01	15.89	51.93	32.21	6.5	181.92	175.42	121.28	99.46	36.77	45.95	9.18	30.63	19.14

ARAN Differences between runs-60mph																													
S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	S25R1-R3	S25R2-R3	Average	StdDev
10.1	34.23	44.33	29.55	17.59	9.32	22.04	12.72	14.69	6.59	11.61	32.14	20.53	21.43	10.29	20.87	63.7	42.83	42.47	21.42	23.37	33.9	10.53	22.60	11.70	11.19	164.95	153.76	109.97	85.73
1.76	20.81	19.05	13.87	10.53	0.96	9.77	10.73	7.15	5.39	24.75	35.22	10.47	23.48	12.42	3.17	11.32	14.49	9.66	5.84	7.59	16.57	24.16	16.11	8.29	56.07	12.17	43.9	37.38	22.66
0.82	30.56	31.38	20.92	17.41	0.87	34.96	35.83	23.89	19.94	11.48	3.75	15.23	10.15	5.85	3.99	27.55	23.56	18.37	12.61	11.65	1.32	10.33	7.77	5.62	29.85	12.85	42.7	28.47	14.97
15.74	45.16	29.42	30.11	14.72	11.42	1.5	12.92	8.61	6.21	44.54	9.14	53.68	35.79	23.52	85.87	50.68	35.19	57.25	25.97	15.45	1.39	16.84	11.23	8.55	9.59	3.24	6.35	6.39	3.18
15.21	5.8	9.41	10.14	4.75	9.05	58.77	67.82	45.21	31.64	3.86	37.64	41.5	27.67	20.71	9.07	0.86	9.93	6.62	5.01	19.61	33.92	14.31	22.61	10.14	117.3	79.89	37.41	78.20	39.97
14.77	20.17	5.4	13.45	7.47	288.28	67.46	220.82	192.19	113.16	90.49	76.86	13.63	60.33	41.01	48.72	115.29	66.57	76.86	34.46	8.9	6.52	2.38	5.93	3.30	20.43	4.85	15.58	13.62	7.97
18.02	2.84	15.18	12.01	8.07	151.47	18.45	169.92	113.28	82.64	309	357.09	48.09	238.06	166.27	49.84	208.16	158.32	138.77	80.95	10.83	40.09	29.26	26.73	14.79	46.86	5.93	40.93	31.24	22.12
14.29	108.85	123.14	82.09	59.15	46.77	211.08	257.85	171.90	110.86	44.78	65.62	110.4	73.60	33.53	17.93	37.53	19.6	25.02	10.87	15.52	23.35	7.83	15.57	7.76	1.51	46.53	48.04	32.03	26.44
3.67	98.21	94.54	65.47	53.55	0	152.74	152.74	101.83	88.18	85.59	130.81	45.22	87.21	42.82	90.65	47.38	138.03	92.02	45.34	14.19	0.7	14.89	9.93	8.00	45.11	57.86	12.75	38.57	23.25
37.62	115.98	78.36	77.32	39.19	27.09	166.06	138.97	110.71	73.67	0.33	29.95	30.28	20.19	17.20	15.91	44.72	60.63	40.42	22.67	246.31	102.79	143.52	164.21	73.96	28.89	16.19	12.7	19.26	8.52

ICC Differences between runs-40mph

S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R2	S23R1-R3	S23R2-R3	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R2	S24R1-R3	S24R2-R3	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R2	S25R1-R3	S25R2-R3	Average	StdDev
12.87	3.58	9.29	8.58	4.69	4.77	15.26	10.49	10.17	5.25	32.13	33.65	1.52	22.43	18.13	94.63	106.35	11.72	70.90	51.59	56.75	19.36	76.11	50.74	28.85	167.85	6.02	173.87	115.91	95.22
3.93	3.84	0.09	2.62	2.19	3.61	3.63	0.02	2.42	2.08	275.15	111.24	163.91	183.43	83.68	84.89	25.22	59.67	56.59	29.95	1.76	6.87	8.63	5.75	3.57	134.33	21.11	113.22	89.55	60.21
15.1	13.29	1.81	10.07	7.21	9.33	5.81	3.52	6.22	2.93	38.62	10.89	27.73	25.75	13.97	11.5	13.74	25.24	16.83	7.37	50.34	11.8	38.54	33.56	19.75	2.63	28.51	31.14	20.76	15.76
10.38	3.04	7.34	6.92	3.69	10.38	11.58	21.96	14.64	6.37	11.15	26.09	14.94	17.39	7.77	126.46	71.18	55.28	84.31	37.36	23.94	8.92	15.02	15.96	7.55	82.83	36.58	46.25	55.22	24.39
5.94	4.22	1.72	3.96	2.12	1.39	24.14	22.75	16.09	12.75	60.95	61.41	0.46	40.94	35.06	235.33	8.37	226.96	156.89	128.69	2.15	7.83	9.98	6.65	4.05	9.95	0.54	9.41	6.63	5.28
16.92	0.28	16.64	11.28	9.53	10.24	2.96	7.28	6.83	3.66	7.6	27.57	19.97	18.38	10.08	44.82	24.1	68.92	45.95	22.43	33.21	31.08	2.13	22.14	17.36	26.68	31.01	4.33	20.67	14.32
12.89	15.62	2.73	10.41	6.79	42.75	0.46	42.29	28.50	24.28	190.72	152.78	37.94	127.15	79.55	133.67	60.59	73.08	89.11	39.09	15.93	41.13	25.2	27.42	12.75	45.11	20.91	24.2	30.07	13.13
2.4	3.01	0.61	2.01	1.25	33.88	44.99	11.11	29.99	17.27	33.28	4.48	28.8	22.19	15.50	59.63	22.48	82.11	54.74	30.11	33.47	5.8	39.27	26.18	17.89	69.03	49.24	19.79	46.02	24.78
7.15	2.32	9.47	6.31	3.65	40.85	21.23	19.62	27.23	11.82	46.31	26.64	19.67	30.87	13.82	172.26	93.82	78.44	114.84	50.32	11.8	15.85	4.05	10.57	6.00	46.84	22.59	24.25	31.23	13.55
0.85	7.87	7.02	5.25	3.83	0.38	31.85	31.47	21.23	18.06	5.64	3.94	1.7	3.76	1.98	38.36	5.52	32.84	25.57	17.58	31.25	11.58	19.67	20.83	9.89	87.41	81.83	5.58	58.27	45.72

ICC Differences between runs-50mph

S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R2	S23R1-R3	S23R2-R3	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R2	S24R1-R3	S24R2-R3	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R2	S25R1-R3	S25R2-R3	Average	StdDev
6.04	19.26	13.22	12.84	6.62	13.52	0.83	12.69	9.01	7.10	18.81	20.93	2.12	13.95	10.30	95.73	92.52	3.21	63.82	52.51	34.46	19.67	14.79	22.97	10.24	180.99	16.25	197.24	131.49	100.13
0.87	12.04	11.17	8.03	6.21	6.14	17.23	11.09	11.49	5.56	273.57	109.35	164.22	182.38	83.60	105.81	42.07	63.74	70.54	32.41	5.74	14.54	8.8	9.69	4.47	89.8	13.99	103.79	69.19	48.32
1.6	23.89	22.29	15.93	12.43	1.06	26.5	25.44	17.67	14.39	31.85	15.26	16.59	21.23	9.22	48.97	32.4	16.57	32.65	16.20	101.4	23.83	77.57	67.60	39.73	23.48	24.24	47.72	31.81	13.78
3.64	14.4	18.04	12.03	7.49	12.16	10.99	23.15	15.43	6.71	78.31	65.62	12.69	52.21	34.81	28.71	30.41	59.12	39.41	17.09	21.97	1.25	20.72	14.65	11.62	52.62	59.69	7.07	39.79	28.56
8.67	7.48	1.19	5.78	4.02	1.67	22.81	24.48	16.32	12.71	13.91	27.48	13.57	18.32	7.93	74.29	159.32	233.61	155.74	79.72	14.4	5.14	19.54	13.03	7.30	37.17	53.13	15.96	35.42	18.65
4.26	18.08	22.34	14.89	9.45	4.27	20.51	16.24	13.67	8.42	162.79	208.26	45.47	138.84	84.00	11.66	22.57	34.23	22.82	11.29	21.71	28.69	6.98	19.13	11.08	44.52	42.77	1.75	29.68	24.20
0.63	26.69	26.06	17.79	14.87	4.49	39.81	35.32	26.54	19.23	12.42	97.02	109.44	72.96	52.80	78.28	68.65	9.63	52.19	37.17	9.29	8.86	18.15	12.10	5.24	40.65	68.39	27.74	45.59	20.77
0.5	0.4	0.9	0.60	0.26	13.39	1.05	12.34	8.93	6.84	9.59	6.91	2.68	6.39	3.48	27.62	42.12	14.5	28.08	13.82	1.72	9.43	7.71	6.29	4.05	19.15	3.97	23.12	15.41	10.11
5.46	10.37	4.91	6.91	3.01	10.94	31.35	20.41	20.90	10.21	0.94	3.34	2.4	2.23	1.21	228.96	106.61	122.35	152.64	66.56	0.27	0.53	0.8	0.53	0.27	19.68	41.31	21.63	27.54	11.96
13.45	46.75	33.3	31.17	16.75	123.12	200.9	77.78	133.93	62.27	3.06	2.56	0.5	2.04	1.36	18.77	17.31	1.46	12.51	9.60	6.05	11.21	17.26	11.51	5.61	97.29	101.82	4.53	67.88	54.91

ICC Differences between runs-60mph

S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R2	S23R1-R3	S23R2-R3	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R2	S24R1-R3	S24R2-R3	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R2	S25R1-R3	S25R2-R3	Average	StdDev
8.53	27.89	19.36	18.59	9.70	0.47	7.52	7.99	5.33	4.21	26.7	47.51	20.81	31.67	14.03	108.93	104.98	3.95	72.62	59.50	33.12	37.79	70.91	47.27	20.60	162.73	18.72	181.45	120.97	89.04
8.38	22.61	14.23	15.07	7.15	4.41	21.77	17.36	14.51	9.02	272.53	105.6	166.93	181.69	84.44	84.21	22.17	62.04	56.14	31.44	5.52	15.54	10.02	10.36	5.02	153.36	79.92	233.28	155.52	76.70
7.48	37.73	30.25	25.15	15.76	1.86	24.09	25.95	17.30	13.40	35.51	25.68	9.83	23.67	12.96	34.66	49.63	14.97	33.09	17.38	81.16	45.47	35.69	54.11	23.93	31.29	35.83	67.12	44.75	19.51
0.73	11.94	12.67	8.45	6.69	8.52	34.44	25.92	22.96	13.21	62.22	90.25	28.03	60.17	31.16	35.14	164.13	128.99	109.42	66.68	5.85	2.1	3.75	3.90	1.88	37.58	3.88	33.7	25.05	18.44
3.84	3.91	0.07	2.61	2.20	8.35	11.31	2.96	7.54	4.23	2.72	38.3	41.02	27.35	21.37	54.25	254.32	308.57	205.71	133.95	16.43	4.3	20.73	13.82	8.52	45.96	105.36	59.4	70.24	31.15
3.12	11.93	8.81	7.95	4.47	7.91	28.27	20.36	18.85	10.26	164.65	255.64	90.99	170.43	82.48	20.34	9.89	30.23	20.15	10.17	6.93	29.68	36.61	24.41	15.53	14.87	29.77	14.9	19.85	8.59
4.84	41.1	45.94	30.63	22.46	4.88	108.75	103.87	72.50	58.61	8.54	161.08	169.62	113.08	90.63	92.06	17.09	74.97	61.37	39.29	43.38	32.54	10.84	28.92	16.57	9.6	83.84	74.24	55.89	40.38
2.83	5.89	3.06	3.93	1.70	5.61	32.82	27.21	21.88	14.37	8.64	17.41	26.05	17.37	8.71	54.5	64.41	118.91	79.27	34.68	21.91	69.55	47.64	46.37	23.85	30.51	15.91	46.42	30.95	15.26
5.37	12.89	7.52	8.59	3.87	9.15	46.82	55.97	37.31	24.82	12.23	29.96	42.19	28.13	15.06	166.42	119.53	46.89	110.95	60.23	10.32	14.01	3.69	9.34	5.23	74.68	15.32	59.36	49.79	30.82
13.54	77.32	63.78	51.55	33.60	104.09	263.71	159.62	175.81	81.03	3.02	10.64	13.66	9.11	5.48	24.8	9.5	15.3	16.53	7.72	14.02	11.85	25.87	17.25	7.55	10.82	13.45	2.63	8.97	5.64

Dynatest Differences between runs-60mph

S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R2	S23R1-R3	S23R2-R3	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R2	S24R1-R3	S24R2-R3	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R2	S25R1-R3	S25R2-R3	Average	StdDev
3.96	10.62	6.66	7.08	7.08	0.09	6.38	6.29	4.25	3.61	34.27	5.09	39.36	26.24	18.49	23.98	22.41	46.39	30.93	13.41	112.13	98.44	13.69	74.75	53.32	113.24	120.39	7.15	80.26	63.42
6.97	7.87	0.9	5.25	5.25	5.38	5.56	0.18	3.71	3.06	26.52	16.92	43.44	28.96	13.43	6.85	19.44	12.59	12.96	6.30	13.64	20.52	6.88	13.68	6.82	138.72	96.71	42.01	92.48	48.49
1.1	2.25	3.35	2.23	2.23	3.82	5.51	1.69	3.67	1.91	4.87	7.92	3.05	5.28	2.46	97.82	20.4	118.22	78.81	51.61	22.82	47.94	70.76	47.17	23.98	63.1	80.42	17.32	53.61	32.60
3.32	2.88	0.44	2.21	2.21	1.74	0.61	2.35	1.57	0.88	24.75	37.89	13.14	25.26	12.38	12.24	12.59	24.83	16.55	7.17	7.13	13.84	20.97	13.98	6.92	18.64	9.75	28.39	18.93	9.32
3.37	3.24	0.13	2.25	2.25	1.65	2.84	1.19	1.89	0.85	14.86	23.2	8.34	15.47	7.45	62.19	45.63	16.56	41.46	23.10	35.3	9.88	25.42	23.53	12.81	23.68	1.44	25.12	16.75	13.28
5.84	2.88	2.96	3.89	3.89	9.34	12.83	3.49	8.55	4.72	9.25	11.76	2.51	7.84	4.78	26.37	46.58	20.21	31.05	13.79	26.9	34.15	7.25	22.77	13.92	6.57	39.93	33.36	26.62	17.67
0.05	4.51	4.46	3.01	3.01	1.24	1.26	2.5	1.67	0.72	8.63	8.38	0.25	5.75	4.77	78.46	95.13	16.67	63.42	41.34	3.89	5.39	1.5	3.59	1.96	51.61	48.09	3.52	34.41	26.81
11.72	14.52	2.8	9.68	9.68	6.54	35.6	29.06	23.73	15.24	1.07	2.89	1.82	1.93	0.91	21.04	21.29	0.25	14.19	12.08	15.59	12.43	3.16	10.39	6.46	29.8	29.98	59.78	39.85	17.26
8.21	6.24	1.97	5.47	5.47	37.84	31.68	6.16	25.23	16.80	0.12	8.51	8.63	5.75	4.88	53.4	94.58	41.18	63.05	27.98	2.31	0.2	2.51	1.67	1.28	12.56	15.95	3.39	10.63	6.50
107.63	7.3	114.93	76.62	76.62	26.24	3.61	29.85	19.90	14.22	52.99	61.79	8.8	41.19	28.40	24.19	42.11	17.92	28.07	12.55	42.7	46.83	4.13	31.22	23.55	105.16	109.81	4.65	73.21	59.42

Dynatest Differences between runs-60mph																													
S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	S25R1-R3	S25R2-R3	Average	StdDev
1.62	9.25	7.63	6.17	4.02	3.18	5.34	2.16	3.56	1.62	1.54	21.93	20.39	14.62	11.35	13.69	49.28	35.59	32.85	17.95	34.37	29.53	4.84	22.91	15.84	60.04	38.23	21.81	40.03	19.18
3.02	0.81	2.21	2.01	1.12	5.29	1.6	3.69	3.53	1.85	7.55	9.54	17.09	11.39	5.03	10.26	134.22	144.48	96.32	74.71	1.99	7.04	5.05	4.69	2.54	91.15	50.32	40.83	60.77	26.74
2.09	2.09	4.18	2.79	1.21	2.91	8.2	5.29	5.47	2.65	3.7	23.86	20.16	15.91	10.73	94.46	89.47	183.93	122.62	53.15	17.28	48.84	31.56	32.56	15.80	51.25	64.83	13.58	43.22	26.55
0.25	0.8	1.05	0.70	0.41	6.96	7.31	0.35	4.87	3.92	15.75	4.01	11.74	10.50	5.97	42.75	0.4	42.35	28.50	24.34	1.07	7.92	8.99	5.99	4.30	16.91	27.43	10.52	18.29	8.54
4.33	0.04	4.37	2.91	2.49	4.23	2.45	1.78	2.82	1.27	11.63	3.8	7.83	7.75	3.92	82.61	9.88	92.49	61.66	45.11	13.31	16.39	3.08	10.93	6.97	1.39	13.52	12.13	9.01	6.64
4.47	1.14	3.33	2.98	1.69	28.92	19.49	9.43	19.28	9.75	11.33	1.39	12.72	8.48	6.18	29.32	9.73	39.05	26.03	14.93	2.1	7.92	5.82	5.28	2.95	9.89	18.98	9.09	12.65	5.49
7.59	3.77	3.82	5.06	2.19	1.81	1.22	0.59	1.21	0.61	8.88	4.31	4.57	5.92	2.57	24.98	1.38	26.36	17.57	14.04	0.05	2.14	2.09	1.43	1.19	9.16	38.92	48.08	32.05	20.35
0.23	12.41	12.18	8.27	6.97	2.41	110.35	112.76	75.17	63.03	0.4	1.78	2.18	1.45	0.93	1.88	10.86	12.74	8.49	5.80	2.76	6.89	4.13	4.59	2.10	5.39	2.92	2.47	3.59	1.57
3.57	4.69	8.26	5.51	2.45	12.62	144.56	157.18	104.79	80.07	10.13	4.07	6.06	6.75	3.09	74.82	19.72	55.1	49.88	27.92	2.19	3.08	0.89	2.05	1.10	3.7	3.37	0.33	2.47	1.86
1.6	140.14	141.74	94.49	80.45	0.58	43.95	44.53	29.69	25.21	13.4	6.8	6.6	8.93	3.87	18.3	9.36	8.94	12.20	5.29	15.76	13.07	2.69	10.51	6.90	38.28	19.68	18.6	25.52	11.06

Dynatest Differences between runs-60mph																													
S23L1-L2	S23L1-L3	S23L2-L3	Average	StdDev	S23R1-R	S23R1-R	S23R2-R	Average	StdDev	S24L1-L2	S24L1-L3	S24L2-L3	Average	StdDev	S24R1-R	S24R1-R	S24R2-R	Average	StdDev	S25L1-L2	S25L1-L3	S25L2-L3	Average	StdDev	S25R1-R	S25R1-R3	S25R2-R3	Average	StdDev
15.61	17.84	2.23	11.89	8.44	2.19	1.93	0.26	1.46	1.05	19.81	22.17	2.36	14.78	10.82	25.53	34.33	8.8	22.89	12.97	89.65	63.95	153.6	102.40	46.16	70.15	91.3	21.15	60.87	35.98
6.56	3.2	3.36	4.37	1.90	17.08	8.55	8.53	11.39	4.93	26.42	24.34	2.08	17.61	13.49	24.44	21.74	2.7	16.29	11.85	8.19	0.99	9.18	6.12	4.47	83.19	47.32	35.87	55.46	24.69
0.77	3.95	4.72	3.15	2.09	14.61	7.49	7.12	9.74	4.22	3.46	1.04	2.42	2.31	1.21	81.37	88.67	7.3	59.11	45.02	60.18	9.36	50.82	40.12	27.05	6.12	19.75	25.87	17.25	10.11
2.61	1.6	1.01	1.74	0.81	10.18	9.63	0.55	6.79	5.41	9.52	6.41	3.11	6.35	3.21	72.62	65.85	6.77	48.41	36.22	15.78	0.23	15.55	10.52	8.91	39.07	32.62	6.45	26.05	17.27
2.92	1.33	1.59	1.95	0.85	3.66	2.86	0.8	2.44	1.48	9.2	15.09	5.89	10.06	4.66	59.56	123.44	63.88	82.29	35.70	74.61	82.7	8.09	55.13	40.94	2.63	6.71	4.08	4.47	2.07
12.58	8.97	3.61	8.39	4.51	28.18	0.5	27.68	18.79	15.84	3.51	15.95	12.44	10.63	6.41	63.52	70.35	6.83	46.90	34.87	5.49	0.75	4.74	3.66	2.55	4.19	10.79	6.6	7.19	3.34
5.77	10.01	4.24	6.67	2.99	5.92	10.48	4.56	6.99	3.10	10.93	15.73	4.8	10.49	5.48	25.68	43.64	17.96	29.09	13.18	4.39	5.08	0.69	3.39	2.36	0.05	31.69	31.74	21.16	18.28
10.78	7.88	2.9	7.19	3.99	5.32	2.89	8.21	5.47	2.66	1.41	0.71	2.12	1.41	0.71	69.89	30.67	39.22	46.59	20.62	3.22	9.27	6.05	6.18	3.03	1.8	9.76	7.96	6.51	4.17
1.16	3.48	4.64	3.09	1.77	59.83	55.11	4.72	39.89	30.55	6.37	29.99	36.36	24.24	15.80	222.46	125.38	97.08	148.31	65.76	5.64	51.38	45.74	34.25	24.94	11.29	12.85	24.14	16.09	7.01
50.43	58.6	8.17	39.07	27.07	37.72	35.69	2.03	25.15	20.05	31.19	3.57	27.62	20.79	15.02	49.54	22.04	27.5	33.03	14.56	35.5	100.69	65.19	67.13	32.64	132.34	10.16	122.18	88.23	67.80